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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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*Single- and Dual-Carrier Microwave
Noise Abatement in The Deep Space Network*

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16. Abstract The NASA/JPL Deep Space Network (DSN) microwave ground antenna systems simultaneously uplink very high power S-band signals while receiving very low level S- and X-band downlinks. Tertiary mechanisms associated with certain waveguide transmission line elements and with most antenna reflector elements give rise to self-interference in the forms of broadband noise burst and coherent intermodulation products. A long-term program to reduce or eliminate both forms of interference is described in detail. Two DSN antennas were subjected to extensive interference testing and practical cleanup programs; the initial performance, modification details, and final performance achieved at several planned stages are discussed. Test equipment and field procedures found useful in locating interference sources are discussed. Practices deemed necessary for interference-free operations in the DSN are described. Much of the specific information given is expected to be easily generalized for application in a variety of similar installations. Recommendations for future investigations and individual element designs are given. Appendixes discuss examples of preferred DSN antenna hardware design as well as the application of welding and shielding techniques for interference reduction on large reflector antennas operated with signals over very large dynamic range.			
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PREFACE

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ABSTRACT

The NASA/JPL Deep Space Network (DSN) microwave ground antenna systems simultaneously uplink very high power S-band signals while receiving very low level S- and X-band downlinks. Tertiary mechanisms associated with certain waveguide transmission line elements and with most antenna reflector elements give rise to self-interference in the forms of broadband noise burst and coherent intermodulation products.

A long-term program to reduce or eliminate both forms of interference is described in detail. Two DSN antennas were subjected to extensive interference testing and practical cleanup programs; the initial performance, modification details, and final performance achieved at several planned stages are discussed. Test equipment and field procedures found useful in locating interference sources are discussed. Practices deemed necessary for interference-free operations in the DSN are described. Much of the specific information given is expected to be easily generalized for application in a variety of similar installations. Recommendations for future investigations and individual element designs are given. Appendixes discuss examples of preferred DSN antenna hardware design as well as the application of welding and shielding techniques for interference reduction on large reflector antennas operated with signals over very large dynamic range.

I. INTRODUCTION

The NASA/JPL Deep Space Network (DSN) microwave ground antenna systems simultaneously transmit very high power continuous-wave uplink signals near 2.1 GHz while receiving very low level downlink signals near 2.3 and 8.4 GHz. These systems support command, precision navigation, and telemetry functions (engineering and scientific) to and from unmanned interplanetary spacecraft. The reflector antennas and some transmission line elements are shared by both transmit and receive functions and must therefore handle radio-frequency currents over a large dynamic range: from less than -170 dBmW up to +86 dBmW (400 kw), a range of more than 250 dB.

When operated in the single-carrier mode, troublesome broadband noise bursts (NB) typically occur in the receive band and may result in receiver demodulator loss of lock with uplink power as low as 1 kW, depending on the type of downlink modulation employed.¹ In the dual-carrier mode, both noise bursts and coherent intermodulation products (IMP) falling within the 2.3-GHz receive band become troublesome. For dual carriers of 10 kW each and 6-MHz separation at 2.1 GHz, high-order intermodulation products averaging -135 dBmW, with peaking 30 dB stronger, are typically experienced near 2.3 GHz.²

Although a concerted program to reduce or eliminate the above interference did not begin until mid-1972, previous observations, experience, and study had bounded the problems and resulted in an efficient program. For that reason, this report begins by providing detailed background and early work sections in order to fully apprise the interested reader of our total experience. Next,

¹Noise bursts, in the DSN context, are impulse-like random increases in the receive system noise level, as measured with a predetection noise bandwidth of 1 MHz and postdetection smoothing of 0.1-0.3 sec. With these receiver/detector parameters, the observed duration of an individual burst can exceed a full second.

²Nearly all of the programs and results to be described in this report concentrated on interference in the 2.3-GHz reception band. While particularly energetic noise bursts (>1000 kelvins at S-band) have also been simultaneously observed at X-band, with amplitudes of a few to a few tens of kelvin, no efforts have yet been undertaken to explore either the 4th harmonic of the S-band uplink within the X-band downlink band at approximately 8460 MHz or associated intermodulation products centered on that harmonic. Further work in these areas is required in the near future.

recent work, circa 1972-1975 is described, with emphasis on test methods, modifications, and measured improvements as a function of time at two DSN stations. Recommendations are given regarding construction guidelines and philosophy of maintenance and operations specifically necessary for the operation of a DSN ground station in a noise-interference-free manner. It is expected that personnel in areas of microwave and structural engineering and operations, whether within the DSN or concerned with similar installations, will benefit from the practical field experiences, supporting studies, and conclusions described herein.

II. BACKGROUND

The technical literature has discussed the problems of spurious signal generation by unintentional nonlinear elements since the late 30's and undoubtedly earlier (Ref. 1). In the very early 890/960-MHz DSN systems, low-noise diplexing reception was seriously threatened by broadband noise bursts in large rigid coaxial transmission lines. A solution of noncontacting center conductor "bullet" connections largely reduced the problem (Refs. 2, 3). Early S-band DSN waveguide systems experienced very noticeable broadband noise burst problems (Ref. 4). The introduction of Manned Space Flight Network (MSFN) and Mutual (MSFN-DSN) S-band stations, to support the Apollo Project, included both broadband noise and coherent intermodulation problems (Ref. 5).

In 1966, the first DSN 64-m-diameter reflector antenna Deep Space Station (DSS 14) was constructed at the Goldstone Deep Space Communications Complex (DSCC), California, and initially configured with a single uplink transmitter of 20-kW output and S-band receivers. The broadband noise burst problem was immediately and very noticeably present. A complete engineering description of this antenna and related facilities is available (Ref. 6).

III. EARLY WORK AT DSS 14

Although efforts to be described began soon after the introduction and resultant noise burst performance of this first 64-m-diameter station, only limited progress was realized for several years. The nature of the evolution of the DSS 14 station, which was marked by the introduction of the Tricone Multiple Primary Feed System, X- and K-band listen-only research feeds and

radiometers, 100- to 400-kW-class transmitters for both DSN uplink and planetary radar functions, dual frequency operational S- and X-band simultaneous feeds, and rapid growth of general electronics to support flight project and radio science objectives, was in part responsible for the slow progress. A considerable array of special capability equipment found its way into the DSS 14 station, on both a permanent and temporary basis. Difficulty in ferreting out fundamental built-in defects, as contrasted with the usual mutual interference associated with introduction of new equipments, complicated the early program. A few of the more troublesome interference sources identified early in the program are listed in Table 1. Except for natural phenomena, all required elimination. This posed problems, especially when two or more sources were active simultaneously.

Many additional sources of interference were postulated at this time. Some of the considered (but not identified) interference sources are listed in Table 2. A few of these possibilities deserve comment. Strong VHF sources near 60, 90 or 180 MHz, when mixed with the DSN uplink at 2115 MHz could easily provide interference at 2295 MHz. Mixing could occur in nearby metal structures or on the reflector antenna itself. Further, the DSN S-band traveling wave maser preamplifier (TWM) has a demonstrated sensitivity to certain off-frequency signals. For example, noise output at 2.3 GHz results from milliwatt-level CW input at 2.6 GHz by the following mechanism: Internal nonlinearities multiply the input $\times 4$. This X-band signal in turn mixes with the 12.7-GHz pump and produces a noise output at the 2.3-GHz difference frequency (Ref. 7). A $\times 5$ multiplication of 2080 MHz, to X-band, was also suspected but not identified.

Possibilities of these kinds appeared likely for two reasons. First, strong nearby sources exist at Goldstone (Table 2) despite care exercised in initially locating the facility and its subsites. Secondly, distant sources, in the Goldstone quadrant south through west, which includes the heavily populated Los Angeles Basin, could not be discounted. Troposcatter in the 150- to 300-km range would be roughly equally efficient at VHF or UHF. More distant sources, via ionospheric or meteoric paths, did not appear promising, but source harmonics, either multiplying to the 180-MHz suspect frequency or to S-band directly, caused either by the source itself or ionospheric nonlinearity, were considered because the burst duration at S-band frequently matches VHF observations of

Table 1. Identified interference sources at DSS 14

1. 2.3-GHz signals from other Goldstone site collimation towers by propagation paths including ground microwave data link passive reflectors on adjacent hilltops.
2. Broadband noise from nearby 60-Hz heavy electrical contactor cycling, found by boresighting the entire antenna system (at 2.3 GHz).
3. Coupling of 5.68-MHz transponder drive signal onto 66-MHz exciter drive cable with resultant mixing product near 71 MHz apparently providing weak transmitter output at 2.3 GHz (DSN Block III receiver-exciter system).
4. Local oscillator leakage from a variety of sources but particularly from station test spectrum analyzers.
5. A variety of on-site VHF sources including multipliers, air conditioning equipment, transceivers, and quartz digital thermometers, with point of entry probably at IF.
6. Vehicle ignition noise from heavy trucks and welding equipment, with the apparent point of entry at IF.
7. Natural phenomena, e.g., nearby lightning, with point of entry at 2.3 GHz.

Table 2. Suspected interference sources at DSS 14

1. Demonstrated DSN S-band traveling wave maser preamplifier sensitivity to a variety of off-frequency mixing products, in the DSN high-power transmitter environment.
2. Nearby NASA STADAN station complex with high-power VHF, 1600- and 6200-MHz sources.
3. Nearby Edwards Air Force Base and other facilities including high-power L-band TACAN and S-band surveillance radar sources.
4. Aircraft-borne sources, particularly DME or TACAN interrogation gear.
5. Reflector antenna proximity to 100-meter wind tower; probable structural nonlinearities in the environment of the above sources.
6. Reception via troposcatter or other low-efficiency propagation (rain, aircraft, birds, meteor bursts, harmonic ionospheric scatter).
7. Natural phenomena, e.g., intermittent precipitation static (dumps), cosmic ray showers.

meteor burst reception (fraction to several seconds). An example of low-efficiency propagation was observed with an 80-100 MHz feed on the DSS 14 64-m system in 1968. The recent discovery of pulsars was of sufficient scientific interest to devote a few days to observation. With the antenna pointed at zenith, good quality video was received from a Kansas City television station (2100 km). After computer processing, however, this interference was not a problem.

Because the combined gain and low-noise level of the 64-m receive system at S-band was fully 10 dB more sensitive than earlier 26-m systems, the possibility of a significant discovery during this early period was not completely discounted. In contrast, the "vending machine syndrome" was also present.³

A number of waveguide RF filters (Table 3) were tried without positive results. Further test filtering at the maser output to afford possible needed relief to the receiver first mixer was tried, again without positive results. The VHF spectrum from 50- to 250-MHz was monitored at DSS 14 in a sensitive search for signals correlated with the S-band noise bursts. With the exception of very strong short-duration aircraft signals near 115 MHz bearing to the south of Goldstone, nothing appeared promising. Further, the lack of correlation of S-band interference with the burst-like 115-MHz signals eliminated this postulated mechanism.

Noise bursts during receive-only tracking at DSS 14 occasionally occur. Evidence suggests these are generally due to local sources on the site complex rather than more exotic possibilities.

A. EXTERIOR SOURCES

The antenna reflector surfaces were next investigated on a very limited basis through use of a shielded garment developed by the U. S. Navy (Ref. 8). With the garment it was possible, with relative safety, for a man to walk about the main reflector surface (at zenith attitude) and probe for loose connections of various kinds (trap doors, exposed flexible cable shields, loose hardware,

³That is, the nagging suspicion of interference from some completely frivolous source.

Table 3. Waveguide test filters for suspected internal/
external interference sources at DSS 14

-
1. Modified reflection/absorption harmonic filter in 20-kW transmitter line.
 2. Absorption harmonic filters in 400-kW transmitter line.
 3. 2.3-GHz absorption filter (truncated diplexer) in 400-kW transmitter line.
 4. Additional X-band absorption harmonic filter in 400-kW transmitter line.
 5. 2.3-GHz, 3-cavity bandpass filter in TWM input line.
 6. 2.6-GHz, 3-cavity reject filter in TWM input line.
 7. 2.2-GHz high-pass filter in TWM input line.
 8. Items 3 and 7 combined.
 9. Items 6 and 7 combined.
-

etc.) under 10-20 kW single-carrier powered-up conditions. Very clear results were obtained at both the 26-m DSS 12 and the 64-m DSS 14 stations. Loose hardware was indeed a source of single-carrier noise burst phenomena, and the protective suit itself was an especially annoying source of low-level nonvisible arcing. It was necessary to use rubber boots, gloves, and cotton coveralls in order to make meaningful probes of the suspected hardware.⁴

Additional test data obtained at this time indicated considerable S-band leakage (on the order of -23 dB) through the DSS 14 Cassegrain subreflector panel seams despite the 50 mm-wide aluminum tape used to "seal" these

⁴Later S-band shielding tests of this garment have cast serious doubt as to the safety afforded with such short (14-cm) wavelengths. Even though the metalized Nylon material used exhibits plane wave shieldings of more than 40 dB on continuous samples and never worse than 23 dB on sewn seams and zippers, for the worst polarization orientation, the fact that the shielding is finite and quasi-parallel surfaces exist (the head enclosure, for example) leads to a crude microwave cavity effect with the possibility of enhanced internal fields. For this reason, further use of the garment at centimeter wavelengths is strongly discouraged since prediction of internal field strengths is considered impossible. Use at meter wavelengths, however, appears quite safe.

construction joints.⁵ Also, power density measurements in the areas near the connections of the feed support (quadripod) legs to the apex structure were higher than expected; apparently some forward spillover energy from the feed-horn (in transmission) is channeled up the structural members in a complex way. Both tests indicated the previous assumption of a well-defined (except for diffraction) shadow region behind the subreflector was incorrect, and to some degree poorly bonded hardware in this "twilight" region could be a problem. Further tests at this time from an independent 26-m station with dual-carrier capability (DSS 11) confirmed the growing evidence of extremely microphonic and erratic noise performance of outdoor antenna reflector elements, especially enhanced noise bursts when using dual carriers (Refs. 5, 9).

The positive evidence of noise bursts being caused by exterior sources on the reflecting antenna surfaces led to a cleanup effort at DSS 14, beginning in the early months of 1969. Because of the large size of this antenna structure and the total amount of work needed, determined in part by tests but primarily on a simple visual inspection basis, the approach taken was to clean up very poorly bonded or loose hardware items first and determine the need for further work on the basis of RF testing. Typical items receiving attention on the first few major cleanup "passes" are shown in Table 4.

The preferred solution to a large number of nonessential items was simple elimination. When elimination was not possible, modification was next preferred, with a few items requiring redesign. Although some obviously unbonded hardware was most easily modified by welding, in general, extensive use of this more costly and time-consuming solution was not a part of the early program. Difficulties in upgrading many deficient areas were experienced. Daily tracking commitments by the station precluded major overhauls; most work needed to be completed between spacecraft passes. Perhaps the most difficult undertaking during this period was upgrading the subreflector joints. Figure 1 shows the DSS 14 antenna apex region with subreflector joints retaped using conductive epoxy along the tape edges for ohmic bonding.

⁵ Because of the 7-m diameter of this structure, it is divided into a center hub and 12 radial gores or panels.

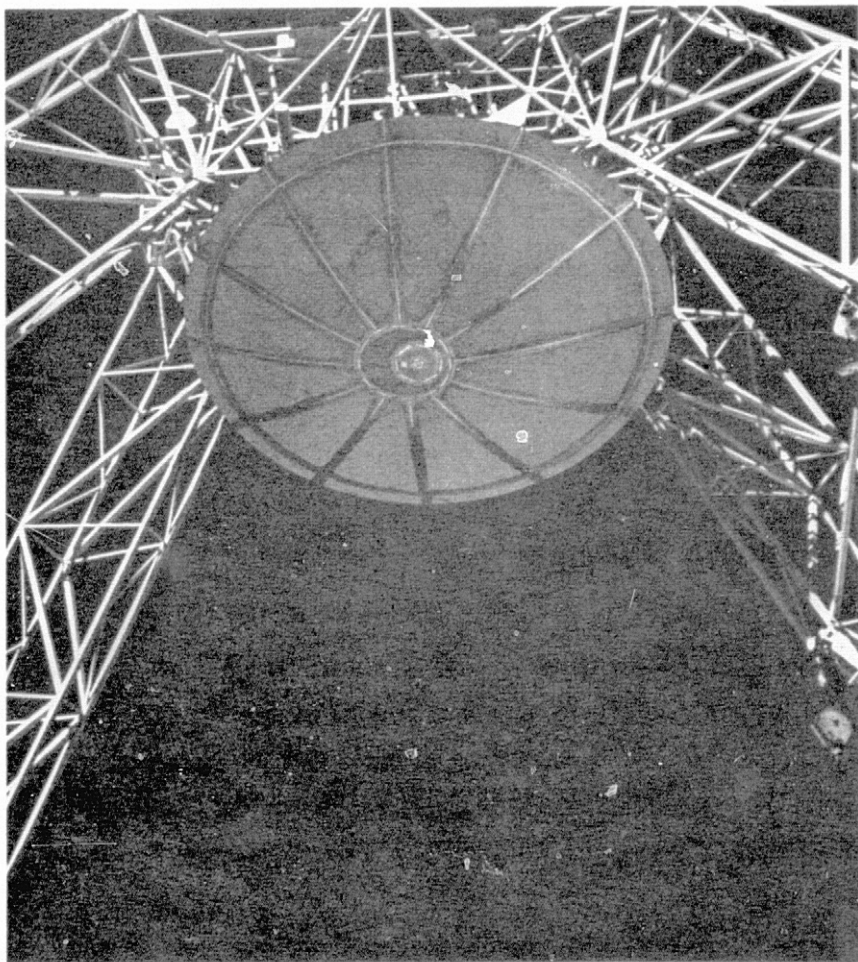


Figure 1. DSS 14 subreflector and apex region

Table 4. Initial outdoor hardware cleanup items at DSS 14

-
1. Selected cabling changes: eliminations and reroutings.
 2. Large feedcone hoist cabling and pulleys previously stowed on two quadripod legs temporarily removed.^a
 3. Ground service hoist winch, cables, pulleys located near the base of one quadripod leg were shielded.
 4. Loose ac conduits, light fixtures on quadripod, floodlights on dish surface modified. "Nuisance" items (outdoor telephones, intercoms, unused junction boxes, etc.) eliminated wherever possible.
 5. Loose or poorly bonded guard rails, handrails, and walkways removed.
 6. Conduit and other poorly bonded clamps and the like removed wherever possible.
 7. Cable tray with exposed flexible cable shields and unshielded cables on one quadripod leg removed. Quadripod leg cable services to the apex installed within all-welded 200-mm-diameter conduit.
 8. Pressed or punched aluminum ladders and steel gratings removed or modified.
 9. Deteriorated 50-mm-wide aluminum tape on all main reflecting panel joints replaced.
 10. Subreflector panel joints improved using conductive epoxy along aluminum tape edges for positive (ohmic) bonding.
 11. Removed heavy loose stored subreflector hoist equipment at the quadripod apex to reduce vibration of the light-skinned subreflector surface.
 12. Removed minor hardware at the quadripod apex in the higher power density regions, including nuisance class items as in 4, above.
-

^aThe DSN 64-m antenna structures are designed to utilize the quadripod legs and elevation drives as crane booms for feedcone and other major element installation.

Work in this category continued intermittently until early 1972, with resultant intermediate and final performance improvements which were a very clear disappointment in relation to the amount of cleanup work done. Figure 2 is a representative sample of noise burst performance during this period. (see footnote 1). The microphonic nature of the noise can be seen during the

elevation-azimuth test. This test consists of rapid deceleration (by application of servo drive brakes) of the entire moving antenna structure. The change in baseline from approximately 23 to 40 K is due to normal steady-state ground and atmospheric noise pickup, as a function of elevation angle.

B. INTERNAL SOURCES

During the time period discussed above, the very high CW power (400 kW) DSN prototype transmitter was introduced at DSS 14. Initial experience with major waveguide arcing and experience gained elsewhere (Refs. 10, 11) led to a significant effort in studying the internal transmission line system and developing special tests for this part of the overall system. A flat plate test reflector was fitted over the S-band feedhorn in order to deflect the transmitted beam to the side and prevent normal illumination of both the hyperboloid subreflector and paraboloid main reflector. Initial tests were erratic and inconclusive because the rectangular (approximately 1 x 2 m) flat plate attaching hardware was found to be a source of serious arcing. An improved flat plate with insulated attachment hardware indicated that internal transmission line noise was also present. The unexpected finding that internal broadband noise exhibited temporal and amplitude characteristics essentially indistinguishable from outdoor noise was initially difficult to accept.⁶ A special test was devised to check the early flat plate results. A high-power (20-kW) water load was considered as a termination for the normal diplexer antenna port, but this would have resulted in roughly a 300 K receive system noise level. A megawatt transmit filter (MTF) was inserted between the diplexer antenna port and the water load. This filter provides a rejection of about 100 dB over the 2270-2300 MHz receive band, with only 0.05 dB of dissipative loss at the uplink band. When inserted, the traveling wave maser is effectively terminated in a nearly loss-free reactance, hence isolated from the water load, and low (15-30 K) receive system noise levels result. This test confirmed the flat plate reflector result; broadband transmission line noise was still indicated. A final test to eliminate the possibility of leakage paths between the exciter/transmitter and receiver systems

⁶As will be described in following sections, later work emphasizing dual-carrier intermodulation problems shows that some distinctions between internal and outdoor intermodulation products are possible.

was done. An 8-hour spacecraft tracking pass was cooperatively arranged in which the transmitter was operated at full power but terminated in its normal calorimetric water load. Since no noise interference was observed, it was concluded that all tests (flat plate, isolated water load, and leakage path) were consistent: transmission line noise was present and surprisingly indistinguishable from outdoor structural noise.

Another test developed at this time involved monitoring the diplexer filter "fourth port." The DSN diplexer is at once a low-pass filter as seen by the transmitter and a "zero-dB" directional coupler at frequencies above 2.2 GHz. One zero-dB path connects the antenna port with the traveling wave maser port. The diagonal path provides zero-dB coupling between the transmitter port and a normally terminated port. Use was made of this port to monitor 2.3-GHz noise either originating in the transmitter and not sufficiently rejected by the MTF or originating in a possible defect within the MTF or diplexer itself. Monitoring with a bandpass filter mixer input test receiver at 2250, 2300, 2350 MHz produced identical results; some noise bursts were present and correlated with the maser output bursts while conversely some maser output bursts did not appear in the test receiver. Since these results were not clear, no conclusions were drawn. In retrospect, the generally poor condition of the overall system at the time suggests that noise bursts were indeed being generated independently on both sides of the diplexer.

An extensive inspection and overhaul of all internal transmission line elements at DSS 14 was then undertaken. Nearly every part was found deficient in one or more ways. Some easily visible cracks and fractures existed, but most cracks were near microscopic. Most waveguide element construction joints were suspect, on a microscopic (microcrack) basis. The pressures and constraints of DSS 14 station tracking commitments again precluded a high-reliability refurbishment. The items with major deficiencies were cleaned of corrosion, flux, paint and metal chips, etc. Warped flanges were refinished, and certain corrosion-preventive measures were undertaken. All waveguide flange faces were treated with a very thin film of nonconducting silicone grease to prevent flange corrosion. A mated pair of good flat ungreased flanges provides an irresistible sink to atmospheric water vapor, apparently by capillary action, despite dry nitrogen pressurization. This

procedure eliminated flange corrosion and previous observation of mild water staining. A second benefit was realized using silicone grease in areas where dissimilar metals must be interfaced (aluminum waveguide switch to copper alloy flange, for example). Although only ohmic tests at dc were done, indicating erratic contacts, all waveguide switch and rotary joint ball bearing assemblies were suspect. The probable lack of infinite isolation in these components suggests some microwave currents must be present at the ball bearings. Without further consideration, a conductive grease was substituted.

The dry nitrogen supply for low-pressure 0.35 N/cm^2 (8 oz/in.^2) protection from water vapor ingress to the waveguide system was improved. The old dry bottled gas system suffered interruption on a near daily basis. A system comprised of a pair of 50-liter liquid dewars, arranged in an active/standby automatic manifold, backed up by an emergency manifold of dry gas bottles with appropriate indicators and alarms was devised for an interrupt-free supply.

Despite all the above efforts, little change in noise burst performance was observed between work periods.

C. DSS 14 OVERALL PERFORMANCE (1972)

1. Noise Bursts

During 1972, DSS 14 was configured with two diplexed 400-kW feedcones. One, the S-band megawatt transmit (SMT), was the initial system to test 400-kW (1000-kW design) components. As such, it was of simplified microwave design and restricted to RHCP (right-hand circular polarization) only. The other feedcone, termed PDS (polarization diverse S-band) allowed simultaneous RCP, LCP, and rotating linear polarizations. In an effort to more fully understand the noise burst problem, which was not yielding to the cleanup activities described above, a special program was set up to determine differences, if any, between the two feedcones (Ref. 12).

The major results of that study are shown in Table 5 and Figure 3. After many days of averaging, it became clear that there was no difference in noise burst performance between the two feedcones (possibly implying external

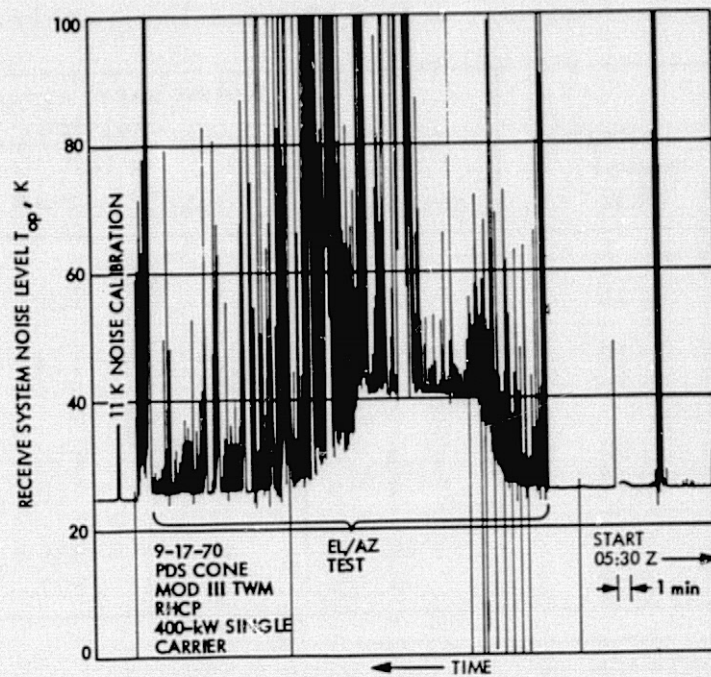


Figure 2. DSS 14 typical noise level performance (1970)

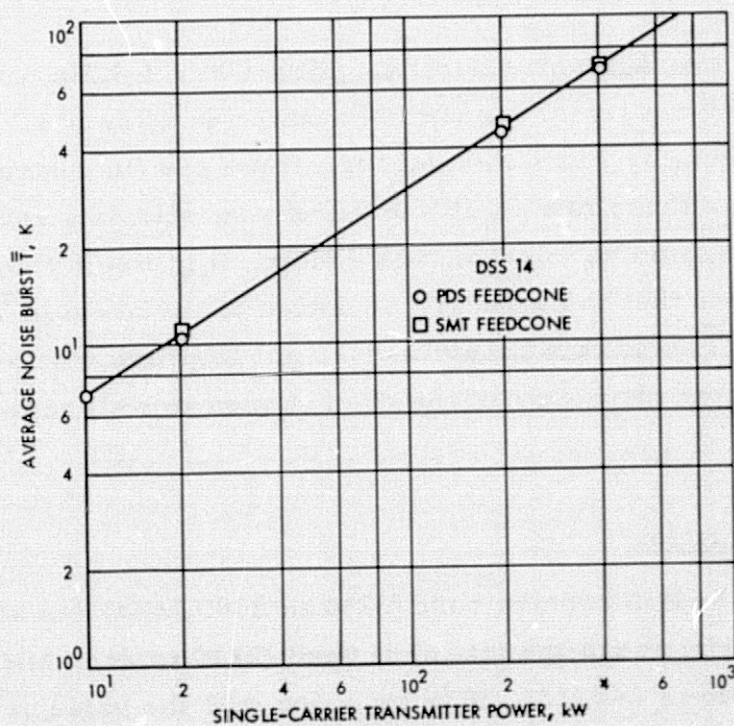


Figure 3. DSS 14 noise-burst analysis (1972)

Table 5. Summary of DSS 14 noise-burst analysis (1972)

Feedcone	Transmitter power, kW	No. of days averaged	Noise burst amplitude, kelvins			Standard deviation of \bar{T} , kelvins
			\bar{T}_{\min} ,	\bar{T}_{\max}	\bar{T} ,	
PDS	10	4	1	120	7	4
PDS	20	15	0	134	10	12
SMT	20	4	2	89	11	8
PDS	200	4	3	176	44	31
SMT	200	1	3	418	47	-
PDS	400	18	2	331	68	52
SMT	400	4	3	397	69	41

source(s)), and that the noise burst amplitude (for this particular system condition) increased with increasing transmitter power:

$$\bar{T} = 1.6 (P)^{0.6}$$

where \bar{T} is the average noise burst amplitude in a 1-MHz bandwidth, in kelvins, and P is the single-carrier transmitter power in kilowatts. This analysis made use of normally scheduled spacecraft passes (in contrast to special test periods) and was therefore an efficient and realistic data source. But the concept of an average noise burst in this context is in itself very 'noisy.' In Table 5 it is seen that the standard deviation of the average \bar{T} is roughly equal to that average \bar{T} , and this behavior does not improve with additional days of data. The random character of the phenomenon is well represented by this result.

2. Intermodulation

Because the DSN receive band (2290 to 2300 MHz) lies at a more or less fixed interval (180 MHz) above the transmit band (2110 to 2120 MHz) in the spacecraft transponder ratio of 240/221, it is apparent that the value or values of N, the integer number or index of the spectral line or lines, potentially appearing in the

receive band under dual-carrier uplink excitation may be approximated as follows:

$$N_{\text{rcvr}} = \frac{180 \pm 5 \text{ MHz}}{(f_1 - f_2)}$$

For instance, if the uplink channel separation ($f_1 - f_2$) were 6 MHz, one would expect line number $N = 30$ to potentially appear within the receive band. Indeed, this is the case, and for each pair of the four Viking Project DSN channel assignments (9, 13, 16, 20), the representative line number indices are $N = 48$ (channels 9 and 20), 75 (channels 9 and 16 or 13 and 20), 133 (channels 9 and 13 or 16 and 20), and 175 (channels 13 and 16). Although none of the several IMP falling in the receive band may lie within an active receive channel for a particular pair of uplink frequencies, these IMP will walk through the receive band at N times the differential uplink tuning, and thereby impact any and all receive channels as the uplinks are operationally tuned as a function of uplink doppler.⁷

Early concerns regarding suspected receive band interference in the Viking mode led to preliminary testing at DSS 14 with carrier separations yielding values of N as low as 31 and as high as 75. First results showed mean values of receiver AGC (when locked to the IMP) to be typically -140 dBmW for $N = 31$, somewhat weaker values for N as high as 45, and no lock (≤ -175 dBmW) for the higher values of N . These data suggested a model of monotonically weaker IMP for increasing N , with the projection of near threshold (and therefore potentially degrading) interference at least for $N = 48$ and possibly for $N = 75$ in the Viking mode. Repeated testing confirmed this by demonstrating $N = 48$ receiver locks with IMP means in the vicinity of -168 dBmW. Consideration

⁷The spectral line index N is not to be confused with the "order" of the intermodulation product. The equations relating IMP frequency and IMP order are (for two carriers) $f_{\text{IMP}} = mf_1 - nf_2$ and intermod order = $m + n$, where f_1 and f_2 are the frequencies of the carriers and m, n are positive integers. For the IMP spectrum centered about the carriers (instead of their harmonics), $m - n = 1$. Assigning $f_1 > f_2$ gives IMP frequencies above the carriers, while $f_2 > f_1$ gives IMP frequencies below the carriers. The intermod order (IO) of the $N = 31$ st line later adopted as a benchmark measure during these programs is $\text{IO} = 2N + 1 = 63$.

of these early mean levels of IMP must recognize the short-term fluctuations which were typically ± 10 dB for 0.1 Hz AGC bandwidth (narrow) and perhaps as much as ± 20 dB for wide AGC bandwidth. Fast indicators (spectrum analyzers) showed frequent peaks 30 dB higher than the means. Figure 4 presents typical mean values of IMP for several values of N and attempts to depict the medium- and long-term variations as well. During these tests, noise burst activity was typically of the order of 100 K peaks and, for a given system condition, was consistently more noisy for dual 40 kW than for single carrier powers of 100 to 400 kW. The reason for dual carriers being more effective than a single carrier of equal or greater power level in stimulating noise bursts is not understood. The effectiveness is consistently evident in both amplitude and time density of the noise bursts.

Experience has shown that, while these IMP are entirely predictable regarding center frequency, they appear to have a spectral width of 10 Hz or so, as if modulated by the random noise burst effect. The overall interference then appears throughout the receive band with clusters of noise energy at the IMP frequencies. In fact, recordings of the usual instrumentation -- receive system noise temperature (T_{op}) and receiver AGC voltage -- show a strong correlation in time between the magnitude and time density of noise bursts and the AGC estimate of IMP power. This is especially true in the short term (seconds), but also generally true in medium (minutes) or long (hours, days) term. Similarly, the noise burst activity and IMP effect appear to be somewhat correlated in magnitude as a function of system condition as if they both arise from the same basic mechanisms (microarcs and/or other nonlinearities). And yet there are some clues that internal waveguide mechanisms may generate noise bursts in somewhat weaker proportion to the IMP mean than do exterior antenna sources. One clue to support this view is the observation that, while operating in an internal mode (without the antenna), the IMP is characterized as having less AGC voltage variance, for a given mean, than a complete antenna system.

While potential tradeoffs and clues to the IMP behavior were being examined, several tests were made to evaluate mean IMP levels as a function of transmitted power per carrier. Incidental equipment problems as well as medium term variations clouded the result. Figure 5 depicts some of the data which suggest a possible 3-dB IMP per dB of balanced transmitter power relationship. Whether or not this is true and whether or not operational use of

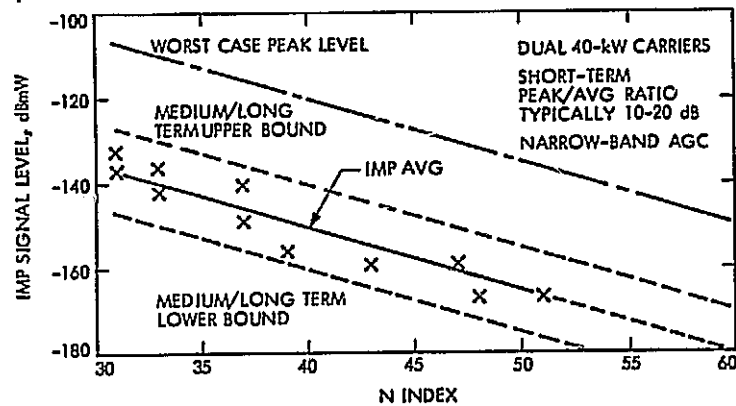


Figure 4. DSS 14 IMP performance as a function of N (1972)

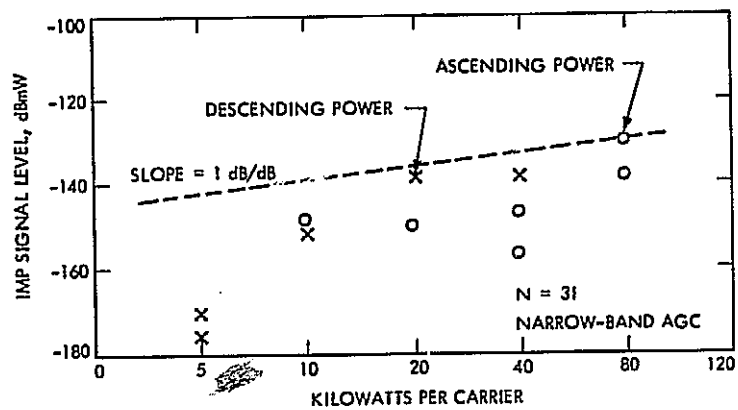


Figure 5. DSS 14 IMP performance as a function of power (1972)

this effect could be exploited under the then-prevailing system conditions would depend strongly upon certain assumptions and conditions of medium-term fluctuation of the IMP at a given power level, which, at that time, appeared risky.

D. SUMMARY OF EARLY WORK AT DSS 14

The results of all the above efforts as of mid-1972 were disappointing. Recalling that much of the outdoor cleanup and internal transmission line work was accomplished roughly simultaneously over a period of approximately three years, a vast improvement might have been expected. In reality, the best estimate of total improvement is only 10 dB in average noise intensity-frequency of occurrence.⁸ In other words, in a broadband noise burst sense, 200-400 kW operations could be conducted at the close of this period about as well as 20 kW operations at the beginning.

Tests for noise bursts were generally conducted before and after the major outdoor cleanup passes mentioned earlier and interposed with major portions of the internal transmission line work. The day-to-day variability in noise burst levels nearly always precluded a statement of definitive results on progress, if any. In fact, the qualitative 10-dB improvement quoted is only possible after the three-year integration time and depended on the availability of two high-power transmitters 10-13 dB apart in level.

Noise bursts were used as a primary measure of progress. The availability of dual-carrier exciters and combiners did not occur until late during the time period under discussion.

It is not considered redundant to repeat that, at the close of this early period, the results were a very clear disappointment in relation to the amount of cleanup work done. Performance remained very erratic, and each new test result tended to further confirm the suspicion that problems existed everywhere - outdoor hardware, common transmission lines, and even an indication of noise

⁸ A qualitative estimate based essentially on the burst optical density as viewed on a strip chart recording of receive system noise level.

originating from the unshared transmitter waveguides or MTF or diplexer itself. The important questions of practicality and costs of cleaning up the interferences could simply not be answered on the basis of these results. More important, the feasibility of conducting further work at DSS 14, which is a very heavily scheduled DSN resource, appeared close to impossible at that time (early 1972). Further, questions of quality of dual-carrier support to the Viking Project required answers no later than that year. Because of these questions, more intensive studies, described in the next section, were begun.

IV. RECENT INVESTIGATIONS AND DSN UPGRADES

The remainder of this report concerns the noise and intermodulation performance upgrade of the DSN 64-m-diameter antenna network consisting of DSS 14 (Goldstone DSCC, California) and the recently completed DSS 43 (Canberra, Australia) and DSS 63 (Madrid, Spain) for the calendar years 1973 and 1974. Important supporting investigations at the 26-m-diameter DSS 13 will also be outlined. A summary of methods developed and utilized to suppress or abate these effects as well as discrete component recommendations will constitute a separate section of this report.

By mid-1972, understanding was far from complete (see Section III-D). To compound the problem, several months' evaluation of simulated Viking Mission operations with dual uplink and resultant intermodulation interference in the downlink receive band indicated a very marginal condition (Ref. 13). Recognizing at that time the interactive nature and probable commonality of causes and potential cures of these two types of interference, an intensive investigation was undertaken later that year at DSS 13, a station dedicated and available to developmental activity. Although for some time a dual-carrier transmit-only capability as well as the listen-only receive configuration had been available there, it was necessary to reconfigure the microwave equipment to permit high-power duplexed operation. While the principal reason for utilizing DSS 13 was the freedom from operational commitments, allowing extended test periods and flexibility for modification as required, a side benefit was the opportunity to simulate a configuration and a set of problems where they had not previously existed and thus to establish the uniqueness or generality of the

DSS 14 phenomena.⁹ As it turned out, the characteristics of the single- and dual-carrier noise bursts and intermodulation products between the two stations were strikingly similar, even to level: i.e., well within 10 dB.

By the end of 1972, progress had been made and confidence attained, and in 1973 rapid extension of the DSS 13 work was applied to the internal microwave and exterior antenna portions of DSS 14. While dual-carrier effects continued as a major element of the activity, the multimission need for single-carrier broadband noise abatement was significant. The immediate concern was Mariner Venus/Mercury, launched late that year, with the newly added complexity of the prototype S/X-band reflex-dichroic feed elements on the DSS 14 antenna (Ref. 14). These prototype outdoor elements of largely riveted construction, when illuminated at S-band, constituted many more potential nonlinearities. Again, the progress achieved (Ref. 15) established the feasibility of suppressing both forms of interference on a large antenna, given the motivation and sustained maintenance necessary to preserve minute RF integrity of the many facets involved.

During 1975, a modification effort will be carried out at the two overseas 64-m stations aimed at achieving essentially noise-free operation at 100-kW single carrier.¹⁰ Procedures and levels of effort judged necessary for operation with 400 kW (as available at DSS 14) or at dual carrier in the 10- to 40-kW range have not been fiscally possible to date. In any event, this base level of modification is considered fundamental to any further commitment to work that may be required in the future.

⁹Of course, these effects were known to be common in a general way (Refs. 4, 5, 9, and 11), but interest was high at the time not only in developing understanding and techniques of control but in establishing levels of variance and operational margins of performance.

¹⁰Specifically, the goal is to limit 100-kW single-carrier NB to 10 K or less. It should be noted that in the interim the Viking Project revised previous dual-carrier requirements to a less strenuous (mission enhancement) classification.

A. DSS 13 DUAL-CARRIER IMPLEMENTATION 1972

Although the original Viking Project dual-carrier commitment specified 64-m station support, any major effort in terms of extensive experimentation with dual carriers at a 64-m station would be extremely difficult. In the past, significant single-carrier noise burst and dual-carrier (restricted to uplink intermodulation product) testing had been accomplished at the Goldstone Microwave Test Facility (MTF) and Venus (DSS 13) 26-m station (Refs. 16, 17). Early in June 1972, a decision was made which would significantly impact DSS 13. The obvious needs of typical DSN antenna reflecting surfaces, together with a 100- to 400-kW class transmitter and low-noise receiver could be most easily achieved by committing DSS 13 to a dual-carrier test program. The results and conclusions obtained from that program could then be assessed with regard to impact upon the 64-m network support of the Viking Project.

Considerable planning was required to outfit DSS 13 with a diplexed dual-carrier test capability, both in terms of the capability itself and desirable test features such as observation ports and air and water RF terminations as shown in Figure 6. A 100-kW klystron was made available. It is interesting to note, for the nominal dual 10-kW carriers, that the power density incident on a 26-m antenna is comparable to dual 40-kW carriers on the DSS 14 64-m antenna. Standard DSN 400-kW filtering was made available from 64-m network spares. Initially, a Block II traveling wave maser (TWM) was made available as the diplexed preamplifier for the DSS 13 receiver. Receivers in use at DSS 13 included the 2295-MHz R&D receiver operated both open loop and 455-kHz closed loop. Open-loop T_{op} instrumentation was available with 1-MHz bandwidth. The XDS 930 computer was used as a digital spectrum analyzer. A low-noise transistorized preamplifier was used with an analog spectrum analyzer (LNSA), for example, to examine receive band IMP, if any, directly from the klystron or from the test probes. A high-power waveguide directional coupler was available to sample forward and reverse transmitter power over a broad band. Four terminations were initially selected: (1) the complete 26-m antenna with S-band radar operational (SRO) feedcone, (2) the SRO feedcone without antenna, by way of a flat plate reflector over the feedhorn, (3) a water load, and (4) an air load called side-looking horn (SLH). A view of the DSS 13 side-looking horn installation is seen in Figure 7. This termination provides the simplest possible radiator, closely coupled in terms of numbers of

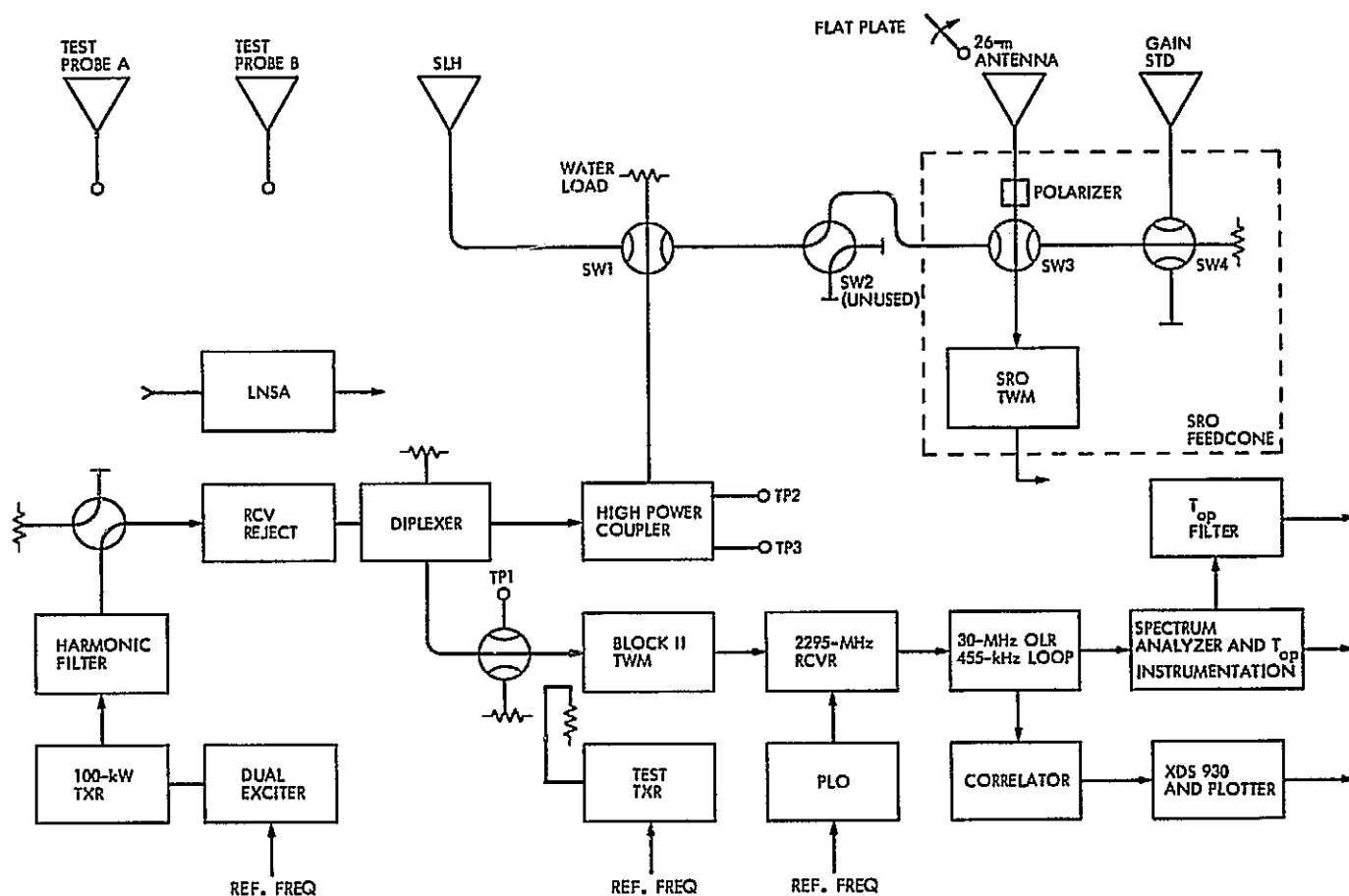


Figure 6. DSS 13 dual-carrier configuration

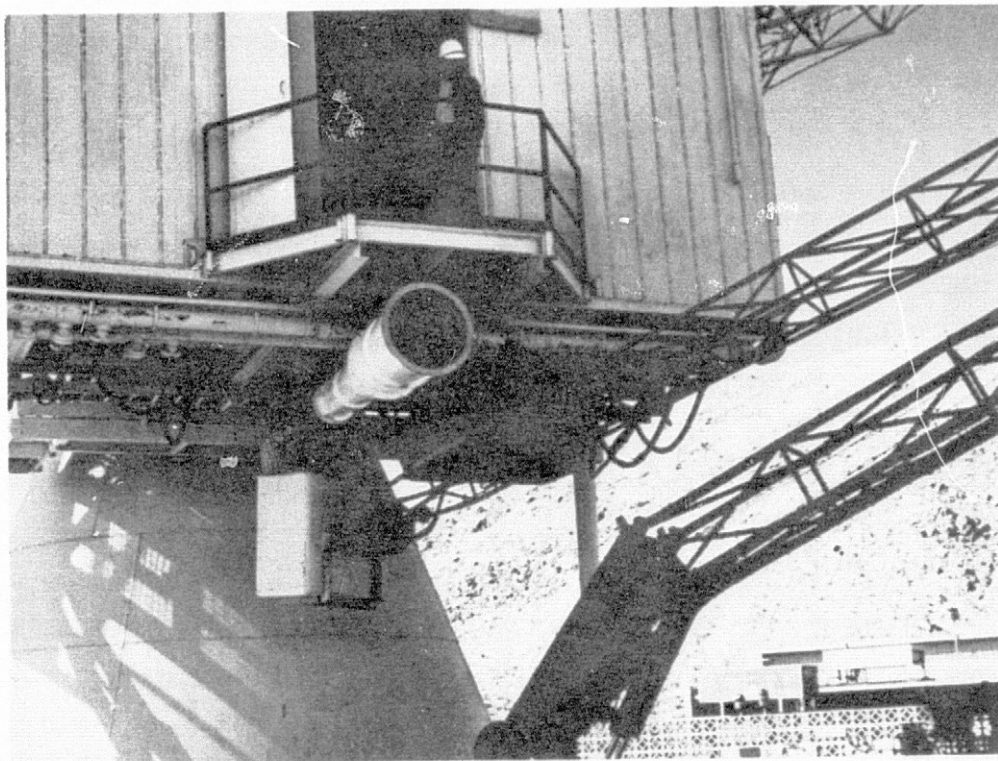


Figure 7. DSS 13 side-looking horn installation

waveguide flanges to the transmitter/filtering/receiver system, housed within the DSS 13 26-m antenna electronics room seen in the upper portion of Figure 7.

At this time (September, 1972), a substantial amount of questionably bonded hardware was removed from the exterior reflecting surfaces of the DSS 13 26-m antenna.¹¹ This hardware included the familiar conduits, lights, clamps, ladders, and other peripheral equipment. The reflecting surface was completely retaped with 100-mm-wide aluminum tape using newly available panel corner interface patches, as shown in Figure 8. Also shown in Figure 8 are the two surface test probes shown in the block diagram (Figure 6). One probe is broadband (waveguide bandwidth) while the other is a highpass filter, cutoff at 2200 MHz. With it, the receive band can be observed without simultaneously coupling in the strong transmitted signals near 2115 MHz.

Figure 9 shows the DSS 13 antenna, as reconfigured in October 1972 for dual-carrier work. During the later stages of reconfiguration (prior to diplexer installation), tests of the transmitter output spectrum using a relocated water load were possible. Those data proved the 100-kW transmitter with dual-carrier excitation was operating properly and that transmit-band (low order) IMP was as anticipated from previous tests or better. In addition, the transmitter output at the receive band was checked for possible IMP. Under no conditions could receive band IMP be detected in the system using only a transmitter sampling coupler and water load elements. The tangential sensitivity of the instrumentation was -35 dBmW referred to the transmitter output port through use of the high-power waveguide directional coupler. After consideration is given for the 160 dB of microwave filtering to be used later, an excess of ~55 dB sensitivity was available to detect a receive band IMP of -140 dBmW, the then-prevailing interference level (at DSS 14).

Considerable attention was given at this time to possible spurious, harmonic, or other mechanisms to explain the previously observed DSS 14 performance. Most if not all of the possible complex mechanisms proposed were checked. None of these possible mechanisms were identified.

¹¹ Essentially upgrading the 26-m structure to approximately the general condition of the 64-m DSS 14 structure, as of that time.

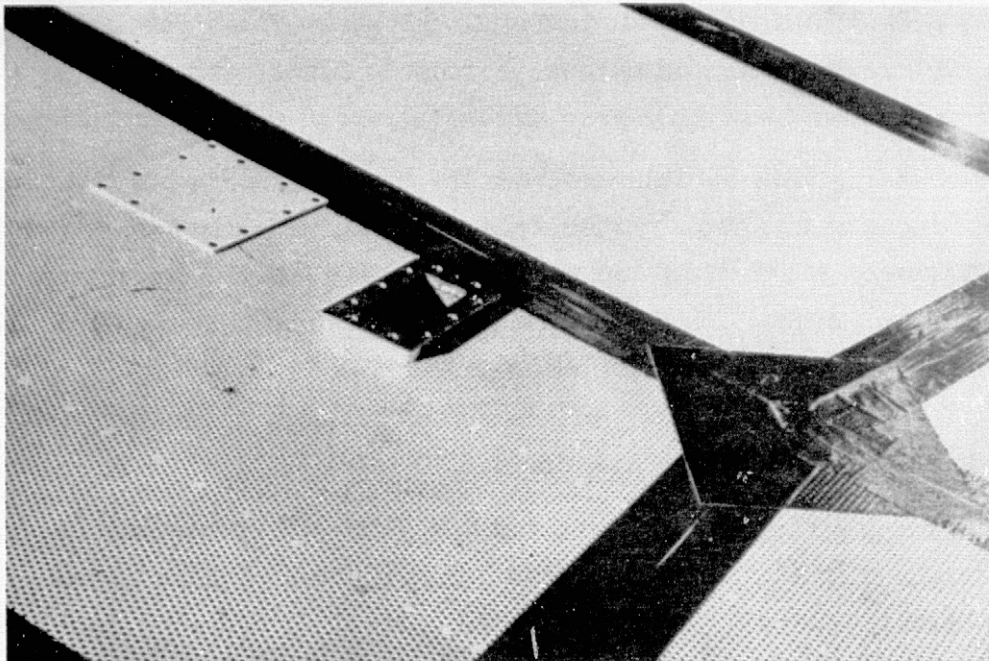


Figure 8. DSS 13 retaped main reflector and test probes

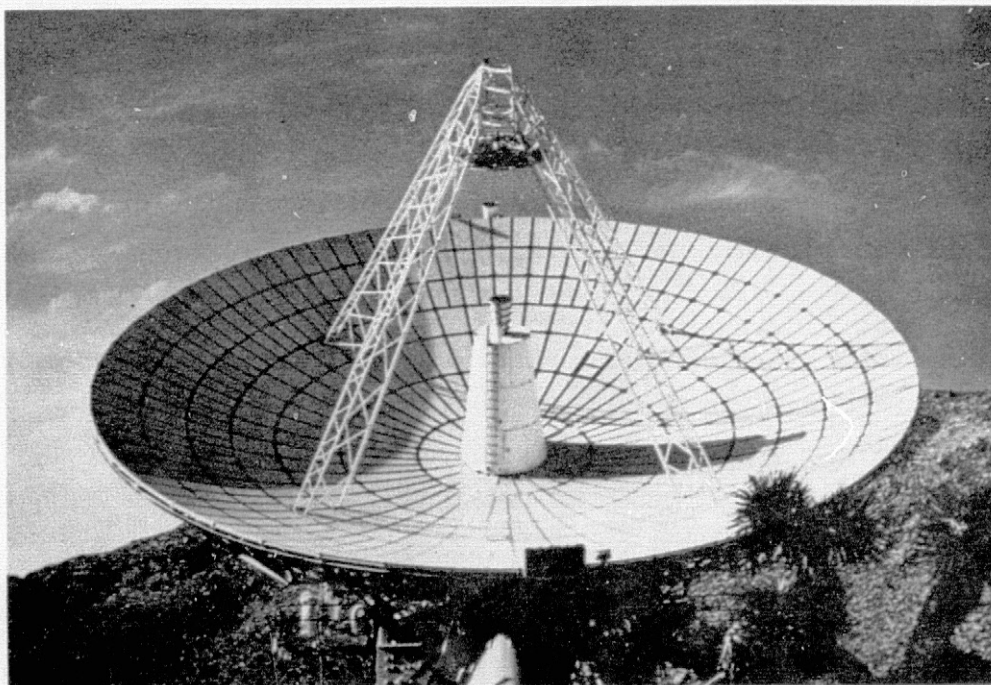


Figure 9. DSS 13 initial dual-carrier configuration

On the basis of the transmitter testing, it was further determined that several standard microwave components (klystron, high power coupler with associated terminations and cables, harmonic filter, and one type of water load) were receive band IMP-free at least down to the levels indicated above.

Proceeding with confidence from the fact that noise burst and intermodulation products at 2290 to 2300 MHz were not sufficiently generated by the 100-kW klystron (<195 dBmW at the TWM input), all four terminations were first tested on October 15, 1972. Nominal test conditions of dual 10-kW carriers with $N = 31$ were adopted. (see footnote 7).

1. Initial Performance, Cleanup, and Results

The air load (SLH) mode showed (via XDS 930 spectrum analyzer) relatively steady -175 ± 5 dBmW IMP with NB less than 1 kelvin at the predicted receive band frequency. The water load (Figure 6) provided comparable performance except that it tended to be mildly microphonic, i.e., shock-sensitive (produced NB and presumably transient IMP) under impact testing. These tests indicated the major noise-producing components were located beyond (antenna side) the SW1 in Figure 6. While these low-level signals were not ignored, the strong -135 ± 10 dBmW IMP with NB > 500 K in a 1-MHz bandwidth observed on the total 26-m antenna system received priority attention. These intermodulation products were, on the average, only a few decibels worse than then present at DSS 14. A hint of the problems to be later encountered was observed when the flat plate reflector was used; no repeatable difference in performance between the flat plate mode and the total antenna system mode was detectable.

There were many questions as to whether the flat plate would be an effective switch (Figure 10) in providing high isolation from the antenna reflecting surfaces. Tertiary mechanisms, such as the previously mentioned support arm arcing, spillover, diffraction and others, might indeed support the observed intermodulation, in view of the tremendous dynamic range spanning uplink ($+76$ dBmW peak) and downlink (-135 dBmW average).

In order to provide a high-reliability answer to such questions, a more effective switch was employed. The subreflector and quadripod were removed as a unit (Figure 11), giving the feedhorn a clear field of view. Surprisingly,



Figure 10. DSS 13 flat plate reflector on SRO feedcone

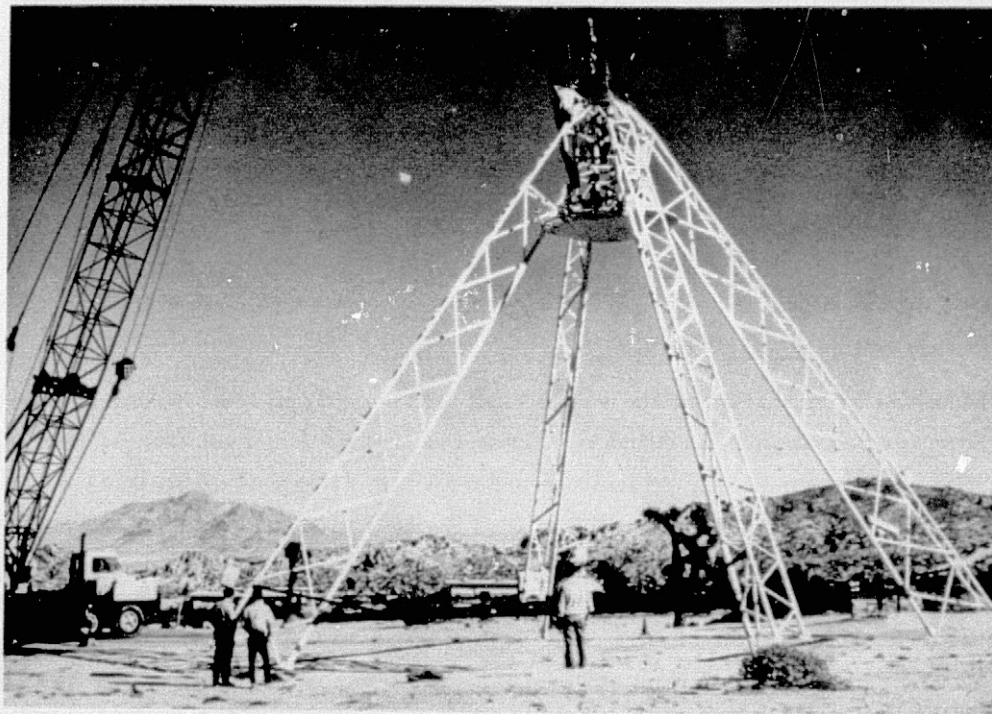


Figure 11. DSS 13 subreflector and quadripod removal

performance with or without the quadripod/subreflector remained essentially the same, with the (not statistically significant) possibility that the mean level dropped 3 dB (-138 dBmW) after the quadripod removal. Samples of the receive system noise temperature, T_{op} , and receiver closed-loop automatic gain control (AGC) IMP instrumentation recordings made during this initial period are available in Figure 12.

In order to resolve the above performance, the diplexed system was terminated into a water load located on the unused SW4 port (Figure 6). Performance remained quite poor (-140 dBmW, 500 K). The waveguide run connecting the 26-m antenna electronics room with the SRO feedcone (SW1 to SW3) was next disassembled, cleaned, acid-etched, relapped, and flanges lightly greased according to current DSN standards (Ref. 18).¹² With the exception of familiar startup burn-in or "RF processing" (Ref. 19), and mild microphonics, the waveguide cleanup was considered successful as measured on the relocated water load.

Performance was also significantly improved when radiating out the clear field of view SRO feedcone, although still not acceptable (-155 dBmW) and quite variable, microphonic, and intermittent. The variability was apparently a function of many things: shock, vibration, solar illumination, rain, and transmitted polarization.

Because the SRO feedcone polarizer and SW3 were the only waveguide-like components not having undergone cleanup recently, they were serviced next, according to the standard. There was still no observable change in performance. Seemingly, everything which was a potential contributor to the problem had either been repaired or eliminated, yet the interference did not yield. At this point, private conjecture concerning the previously assumed linearity of the earth's atmosphere (over such large dynamic range) surfaced and was openly discussed. Finally, for want of a better alternative, the SRO feedhorn itself (a heavy four-piece component not considered a risk item) was nevertheless removed for flange interface lapping and greasing.

While the main feedhorn was being serviced, it was possible (with consideration for proper polarization) to install a water load on top of the polarizer in place of the feedhorn. Performance was of the (then acceptable) -175 ± 5 dBmW class, as anticipated. By use of a clean 2-m-long waveguide extension, it was further possible to try two other horn radiators on top of the waveguide, approximately 0.5 m. above the feedcone roof surface. One horn was low-gain

¹² Essentially upgrading the 26-m internal transmission lines to approximately the condition of the 64-m DSS 14 waveguide system, as of that time.

(+6 dBi) while the other was medium-gain (+16 dBi). Both provided intermittent NB and accompanying IMP of the -145 dBmW class until microwave absorber material was placed around the horn exterior throat regions.¹³ The problems were not eliminated, but significant (~15 dB) reduction was observed.

The serviced main feedhorn was then reinstalled without change in the previous -155 dBmW intermittent class performance. By then adding microwave absorber (now on the feedcone roof surface), continued significant improvement was observed. Without the absorber, hammer testing on interior feedcone walls and roof fully correlated with NB-IMP indicators. One characteristic of all three horns used was that of dominant or single-waveguide-mode excitation. Dominant mode operation is known to diffract significant energy (as much as a few percent) into the rear hemisphere due to untapered E-plane excitation and resultant exterior currents on the horns. Power density surveys in amplitude and polarization about the dominant mode (at the uplink band) SRO feedhorn and feedcone, and then about the hybrid or effectively dual-mode (highly tapered E-plane excitation) SLH, confirmed the expected significant power density difference as well as expected radial field orientations. Circumferential fields were always at least 15 dB below the radial components.

Two significant conclusions were drawn from these tests: (1) dominant mode transmit horn diffraction with normally constructed DSN feedcone exteriors is sufficiently strong to excite poorly bonded metal joints and cause a portion of the microphonic NB/IMP phenomena; and, more important, (2) a comparison of the power density due to diffraction and the power density to be expected later with hyperboloid illumination shows the hyperboloid illumination to be the stronger. Therefore, the feedcone exterior requires sound bonding, independent of horn type, since the hyperboloid illumination dominates. It is interesting to note that the residual (-155 dBmW) problem (1) persisted even though everything initially suspected of being a problem had been repaired or eliminated (waveguides, quadripod), and (2) was finally traced to a completely tertiary mechanism (weak diffraction upon poorly bonded feedcone).

¹³Use of microwave absorber, with the attendant fire hazard at the RF power levels used, is generally discouraged. In this instance, the absence of the hyperboloid reflected field strengths upon the upper feedcone surfaces provided a measure of safety.

During all the above testing, the SLH performance remained consistent at the -175 ± 5 dBmW level, on a daily reference basis. It was impractical to appropriately bond the SRO feedcone exterior within the available time. An approach utilizing an existing partially welded empty feedcone, which was to be more fully welded with the proven (to -175 dBmW) SLH reference horn mounted within, was selected. A simple interior was planned, the only components being a fixed quarter-wave plate polarizer and a waveguide connection to the floor interface. The joint between the SLH and the feedcone roof surface was prepared much like a waveguide flange, with approximately five bolts per wavelength and flat, well-contacting, corrosion-free surfaces protected with grease. The feedcone roof surface, in turn, was welded to the feedcone side-walls, 100 percent. All feedcone sidewall seams, windows and other holes were 100 percent welded. The feedcone doors were insulated rather than welded. Thought was given to the feedcone/reflector interface (a complex aluminum-to-steel joint), but nothing practical was devised prior to installation.

Performance using the welded feedcone working into a clear field of view (Fig. 13) was as expected: NB less than 1 K, with IMP -172 ± 5 dBmW, for an extended test period including shock, vibration, solar illumination, and micro-phonics tests. The flat plate with all joints either welded or insulated was then tested with identical results. It should be noted, however, that such a flat plate test is a necessary but not sufficient test. Diffraction and spillover might still be possible problems after the quadripod/subreflector are installed. In view of the large dynamic range involved, the question still arose: What would the isolation of the flat plate reflector switch be with the quadripod in situ?

Although earlier cleanup work on the main reflector surface and quadripod legs had been done, the test results using the welded feedcone indicated that not nearly enough had been accomplished. It was possible, through a parallel effort, to thoroughly bond the subreflector while the new feedcone was being proof-tested. The vertex plate, beamshaping flange,¹⁴ and, to some extent, hardware behind the rim of the flange in the quasi-shadow zone were bonded together by welding. This parallel effort precluded a precalibration on the

¹⁴The beamshaping flange is the outer annulus of the subreflector.

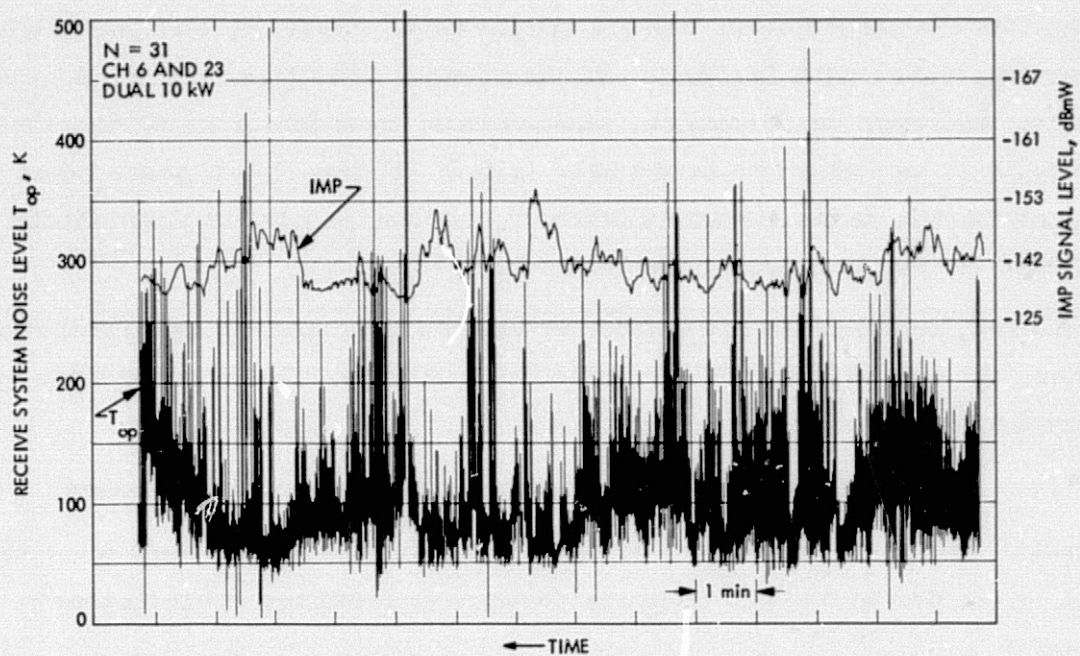


Figure 12. DSS 13 typical noise level and IMP performance (October 1972)

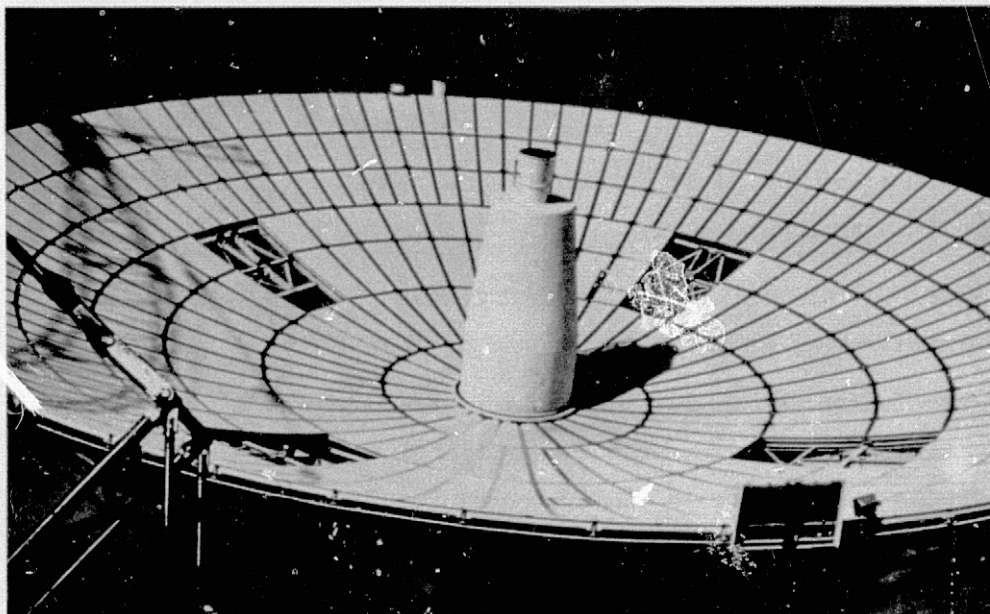


Figure 13. DSS 13 welded feedcone with SLH horn

"as-received" condition of the subreflector. A review of the calculated power densities on the subreflector and initial physical condition, compared with earlier experience with feedcone exterior power densities, initial physical condition, and poor performance, showed that, by a factor of 30 dB, the "as-received" subreflector would have failed. Figure 14, a photo taken when testing of the new feedcone was underway, shows the bonded subreflector being reinstalled in the quadripod (December 7, 1972).¹⁵

After a high degree of confidence was obtained operating with the new feedcone, the quadripod was reinstalled (Figure 15). Questions requiring answers at this point were:

- (1) Are the quadripod/subreflector details adequately bonded?
- (2) Is the feedcone base to reflector (aluminum-to-steel) joint adequate under increased illumination stress from the subreflector?
- (3) Are the complex joints between the quadripod legs/aluminum reflector/steel backup framework adequate?
- (4) Is there sufficient diffracted or "channeled" illumination behind the subreflector to stress the myriad of joints located there which are extremely difficult to bond, insulate, or shield?
- (5) Is the aluminum tape treatment of reflecting panel joints, considered adequate for a single carrier NB solution, sufficient under dual-carrier stress?
- (6) Are any or all of the above weather- or solar-illumination-dependent (intermittent)?

In other words, might a subsidiary failure of any or all items (2) through (6) be misinterpreted as a major failure of item (1)?

Reinstallation of the quadripod included retaping of the quasi-planar joints about the reflecting panels which had been removed for access (Figure 13). Also, attempts were made to shield the aluminum-to-steel interfaces, at both

¹⁵ Examination of Figure 14 frequently raises the question: did the crane boom, cables, et al. intercept the transmitted beam, and if so, were noise bursts and/or intermodulation products generated? It did, and they were.

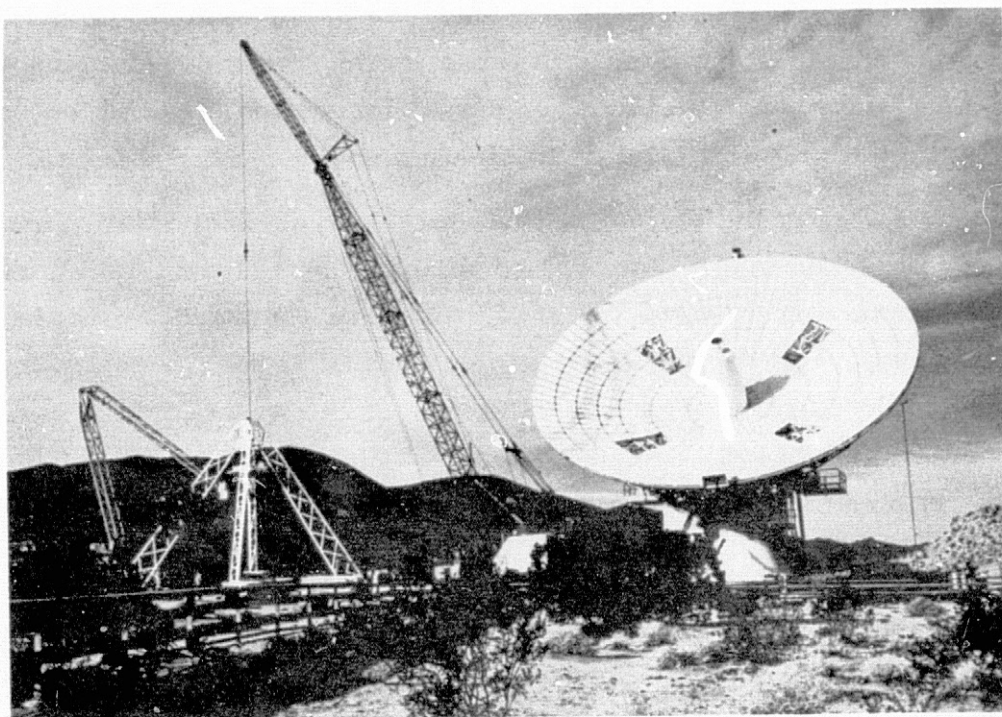


Figure 14. DSS 13 subreflector installation

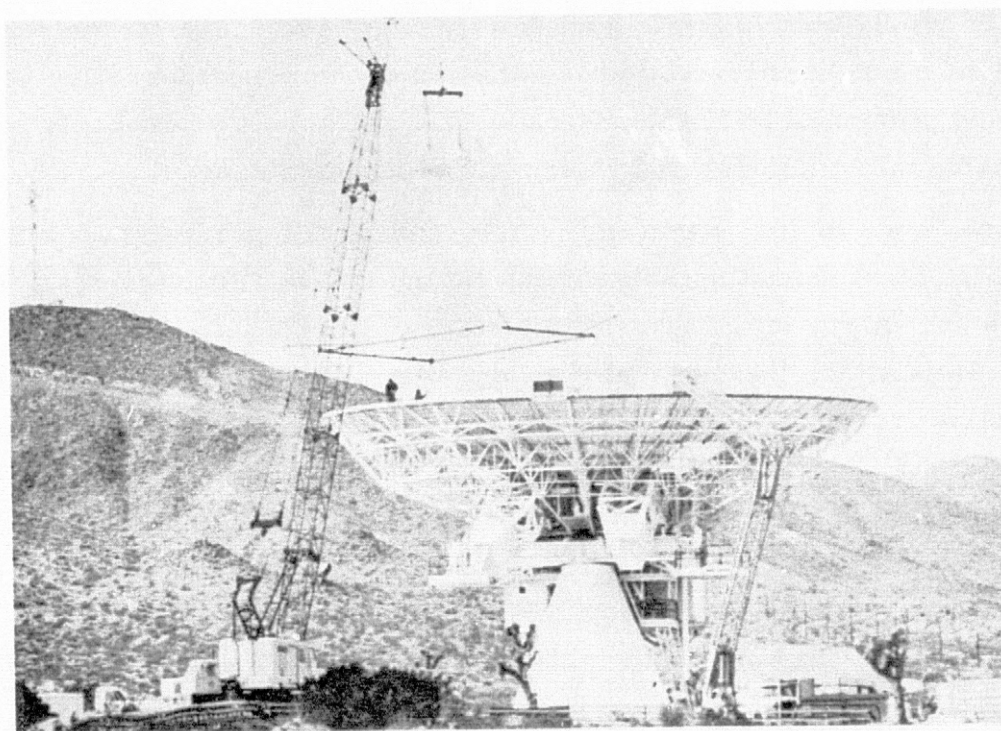


Figure 15. DSS 13 quadripod installation

the bases of the quadripod legs and the feedcone base, using aluminum tape. Because of the physical complexity of these joints, many overlapping and/or wrinkled tape joints became evident on visual inspection, leading one observer to comment on the probability of overdoing otherwise good practice.

Indeed, a strong indication that this might be correct was immediately obtained upon turn-on of the standard conditions: $N = 31$ dual 10-kW carriers. NB with accompanying IMP at -135 ± 5 dBmW were observed, which had the discouraging impact of returning the project to initial poor performance levels. Furthermore, the SLH reference facility was no longer available (used within new feedcone). Wind precluded use of the flat plate at that time. It was decided to remove the questionable metal tape in the regions surrounding the quadripod leg bases. Performance returned to an encouraging -168 dBmW level. The tape was reinstalled to determine repeatability. The -135 dBmW level repeated. The tape was removed a second time. The -168 dBmW level repeated. Confidence was gained in two areas: (1) the tape quality indeed was a problem area, and (2) a few poorly bonded joints (or possibly one) can cause essentially the entire problem. In retrospect, team members witnessing all of the above tests believe the -135 dBmW levels observed probably represent a saturated effect; i. e., a singular addition to, or subtraction from, a large number of poorly bonded joints goes totally unnoticed. The strong suggestion here is that a single uncontrolled installation of some peripheral device on the illuminated portion of DSN antenna reflecting surfaces will probably cause an unacceptable noise impulse and intermodulation interference.

Next, tests of dual-carrier 5-, 10-, and 20-kW pairs with $N = 31$ were conducted. Total operating noise temperature and AGC recordings are seen in Figure 16. A few small intermittents are noticed, increasing with power level.¹⁶ Holding the power level constant at dual 10-kW carriers, other (narrower uplink frequency separation) pairs were tried. $N = 48, 75$ (DSN Channels 9 + 16 and 13 + 20), 130, 134 and 177 all showed the expected acceptable performance and IMP decay with increasing N-index (Figure 17). Another data

¹⁶The AGC "intermittents" in Figure 16 are undoubtedly interference, but cannot all be interpreted as transient IMP.

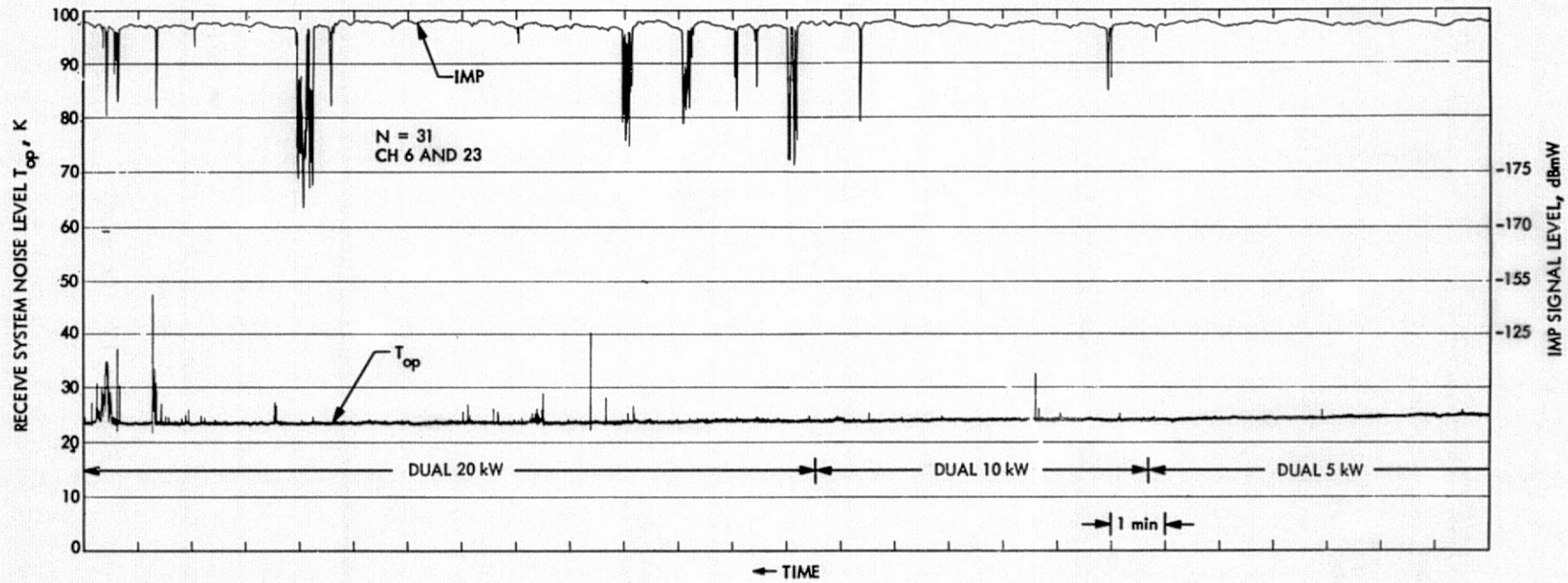


Figure 16. System noise level and IMP performance, DSS 13 antenna (Dec. 7, 1972)

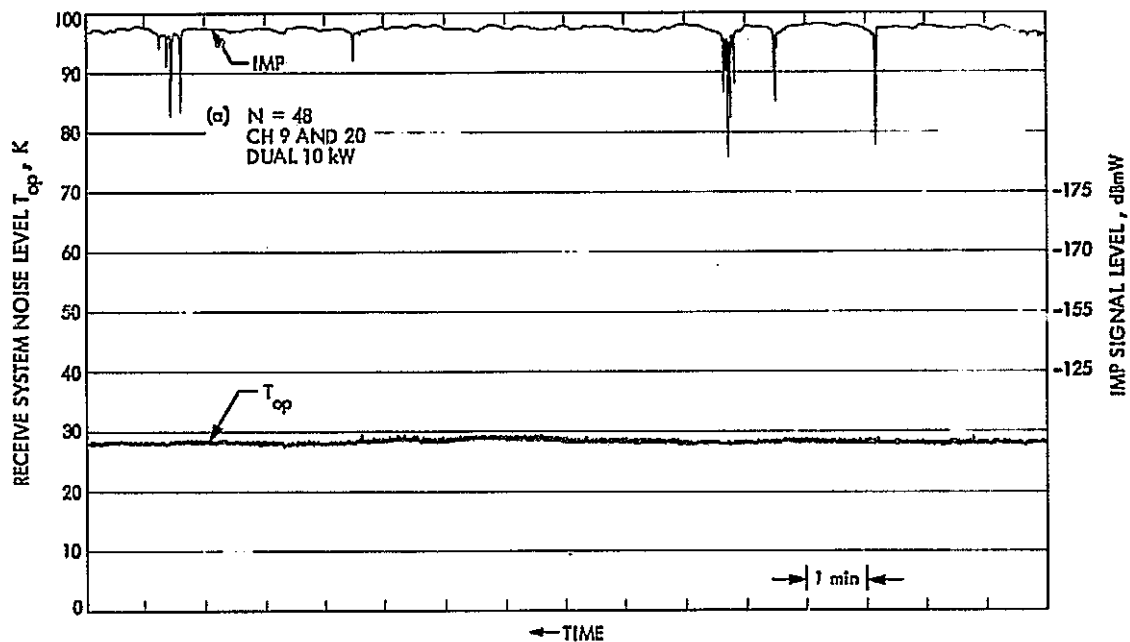


Figure 17. System noise level and IMP performance as functions of N , DSS 13 antenna (Dec. 7, 1972)

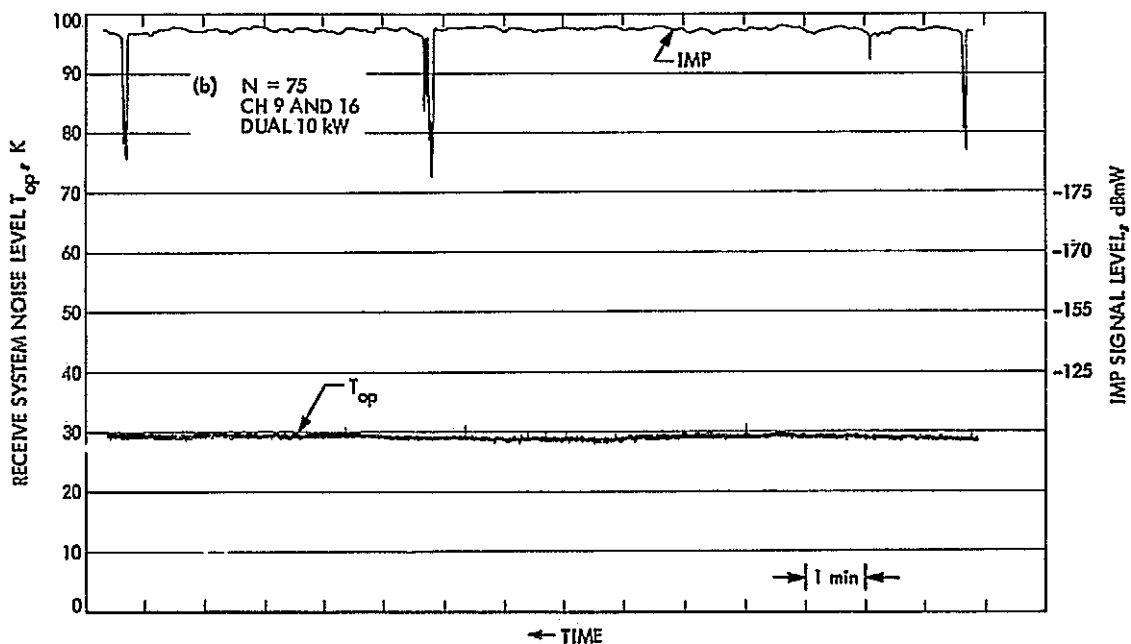


Figure 17 (contd)

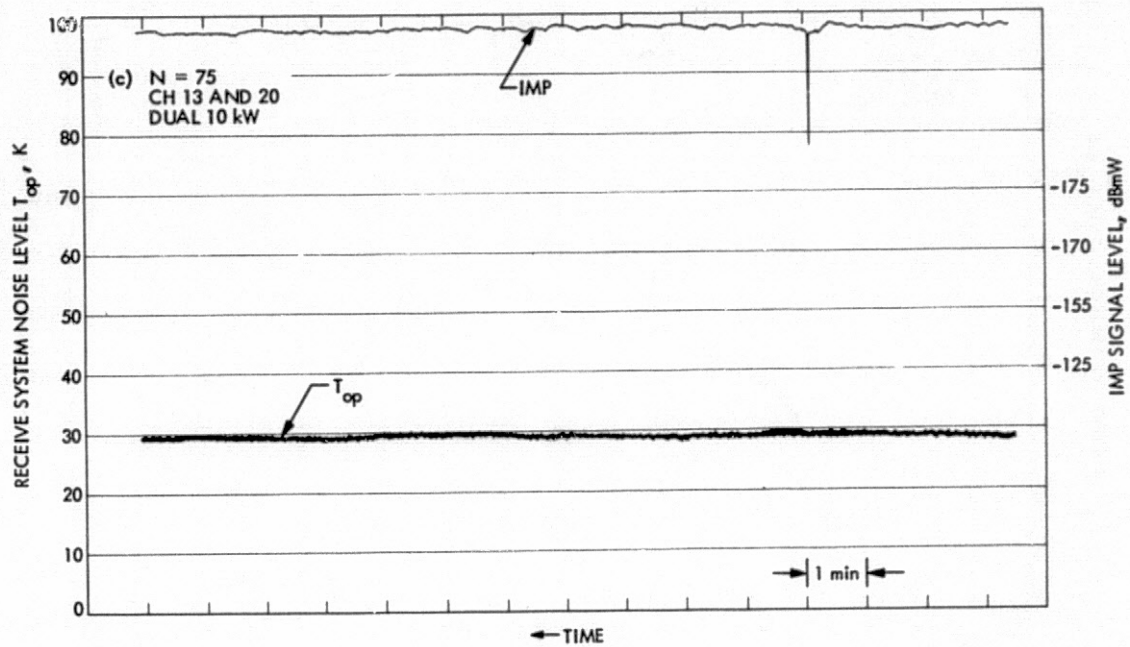


Figure 17 (contd)

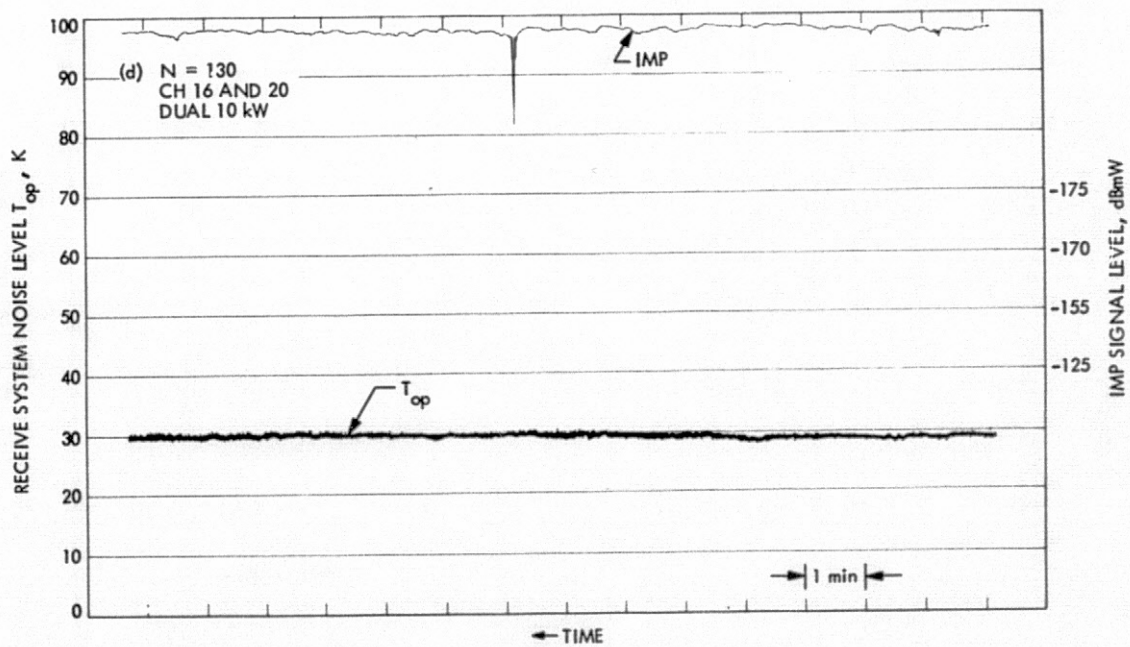


Figure 17 (contd)

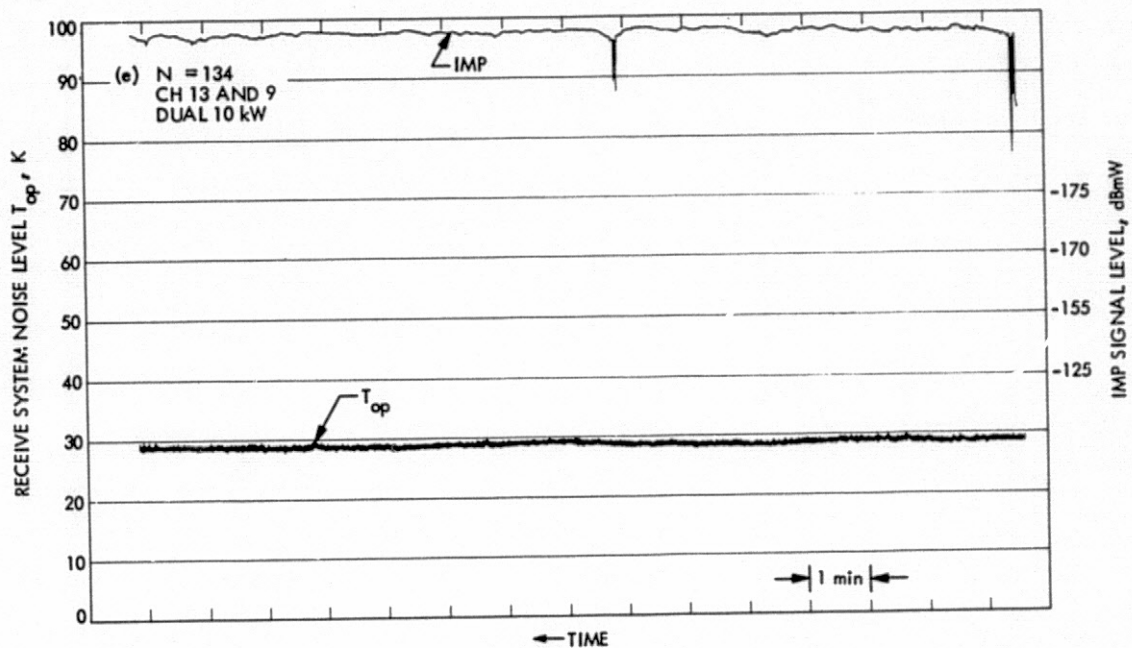


Figure 17 (contd)

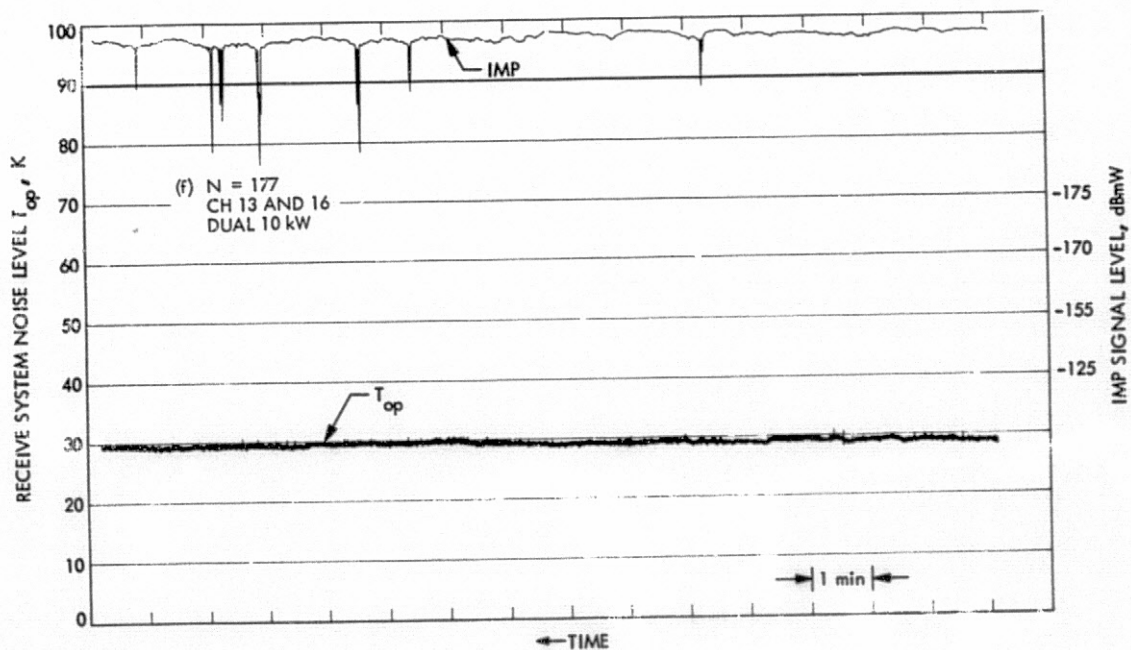


Figure 17 (contd)

run, shown in Figure 18, is less encouraging. Some intermittent condition was present. Perhaps more importantly, inclement weather, particularly heavy fog or rain, impacted the otherwise good performance severely and in a complicated way. Data suggests that a totally wetted antenna surface provides a continuous noise-free reflector while an antenna drying out acts quite intermittent and noisy. These effects remain poorly understood. Even common environmental effects such as solar radiation remained to be more fully examined in the context of heavy, large, outdoor equipment used over a large microwave dynamic range, requiring large numbers of high-quality mechanical connections.

2. Follow-on Activities

Overall results at DSS 13 by mid-December 1972 were such that it was considered possible to achieve comparable results on a 64-m antenna, even with the recognized problems attendant to a much larger structure. No cost-prohibitive measures appeared necessary to initially control the interference problems. On the other hand, the possibility was considered that a difficult and/or costly maintenance regimen might be needed. Significant unknowns, including the residual intermittence at DSS 13, the desire to understand environmental effects, as well as the performance of the scheduled prototype S/X dual-band feed hardware on the 64-m antennas, remained unresolved. From these results it was understood that weather independence might not be possible.

Notwithstanding these difficulties, it was decided at a December 1972 meeting with Viking Project representatives to continue plans to use dual uplinks from each 64-m station. Plans were then made to take advantage of the February-March 1973 downtime at DSS 14 to make whatever tests and modifications as were feasible. In the meanwhile the investigation at DSS 13 was to be completed in a few areas and followed by a long-term evaluation of noise burst and IMP performance, particularly that of the internal waveguide system. To a large extent, further work on the structurally unique DSS 13 antenna exterior surfaces would be dropped due to resource limitations and the need to proceed with the 64-m DSS 14 effort.

Figure 19 summarizes the milestones reached at DSS 13 by the end of 1972. The low-level problem (-175 dBm^2) at $N = 31$ dual 10-kW operation had continually existed. Although this level was acceptable in the Viking context, given the repeatable decay observed with larger N numbers, the long-term

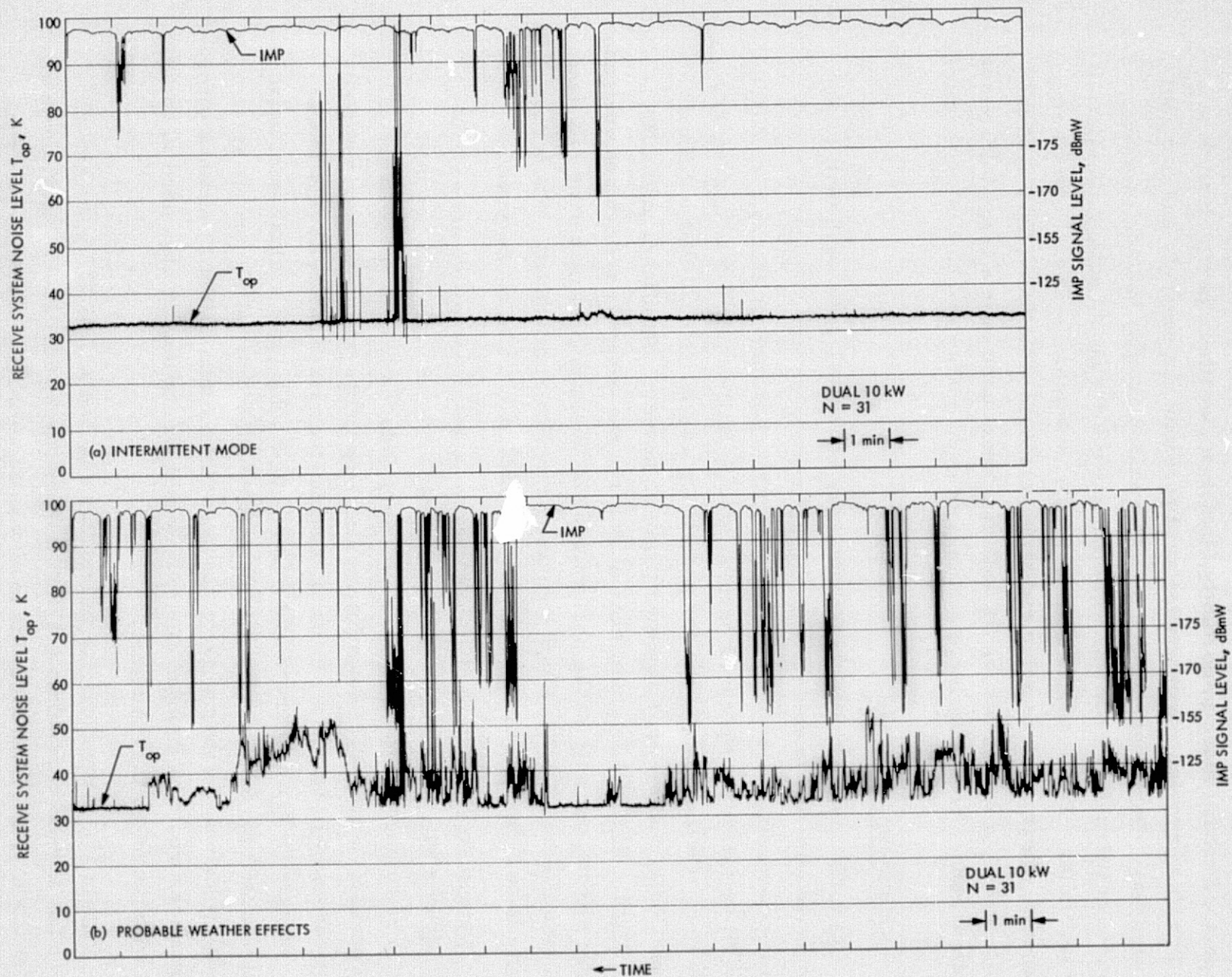


Figure 18. System noise level and IMP performance, DSS-13 antenna (Dec. 8, 1972): (a) during interim mode, (b) during probable weather effects

stability of this level was worrisome. By December 16, the low-level problem had indeed changed for the worse by 10 to 15 dB (Figure 19), even on the simple (cleanest) system using the flat plate reflector, thus essentially eliminating from consideration the outdoor antenna hardware as a source. A new internal source had presumably become active and required investigation.

Throughout the various stages of activity at DSS 13 it had been observed that a difference in interference signatures existed with improving interference level. As the most troublesome high-amplitude noise bursts were subdued, the variance of the IMP level became less. That is to say, with NB in the 100's of kelvin, IMP means were only stable within ± 10 dB, but with NB subdued to a few kelvin the IMP mean was quite stable, within a few dB or better. The knowledge of the probable source location (internal waveguide) and the previous observations of steady IMP at -175 dBmW (now -160 dBmW) led back to the early hypothesis concerning small microcracks within the waveguide system as the source.¹⁷ This proved to be the case, and fully 6 months in early 1973 were devoted to this work. Figure 20 is a block diagram of the simplified system used. The only DSN microwave component not being type-tested in this system is the orthomode transducer used in the prototype SPD (PDS) feedcone for the 64-m subnet¹⁸ (Figure 21). A full description of results obtained on the DSS 13 waveguide system during the follow-on period (primarily very low-level IMP abatement) will be deferred to a later section and integrated with the DSS 14 results for completeness.

Throughout the dual-carrier effort at DSS 13, the need was felt for a one-port diode mixer device which could sample the two transmitter carriers and generate a stable IMP when desired to verify the ability of the receiving system to detect low-level IMP. This device was designed and built and was in constant use at DSS 13 to check the operational readiness of the dual-carrier

¹⁷To some extent, the previously recognized microcrack phenomenon (thought to be stress concentration cracks) had not been considered as a viable source in the context of such large intermod orders (i.e., ≥ 63).

¹⁸This component, of massive one-piece copper construction using electric discharge machining (EDM), was considered of conservative design, hence an acceptable (for the time being) risk. As later DSS 14 results will show, this was a valid assumption.

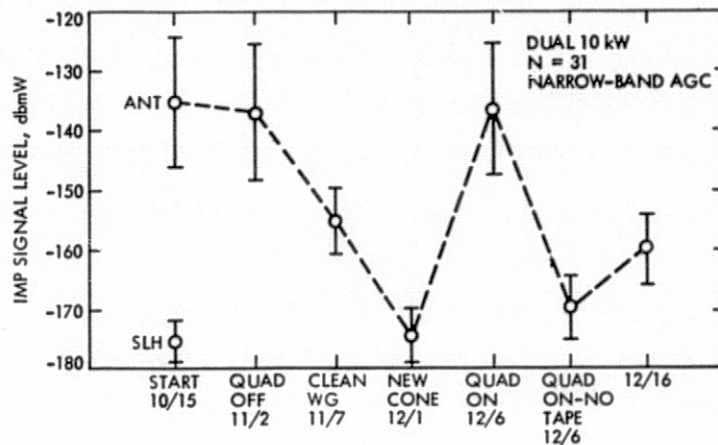


Figure 19. DSS 13 IMP performance milestones (1972)

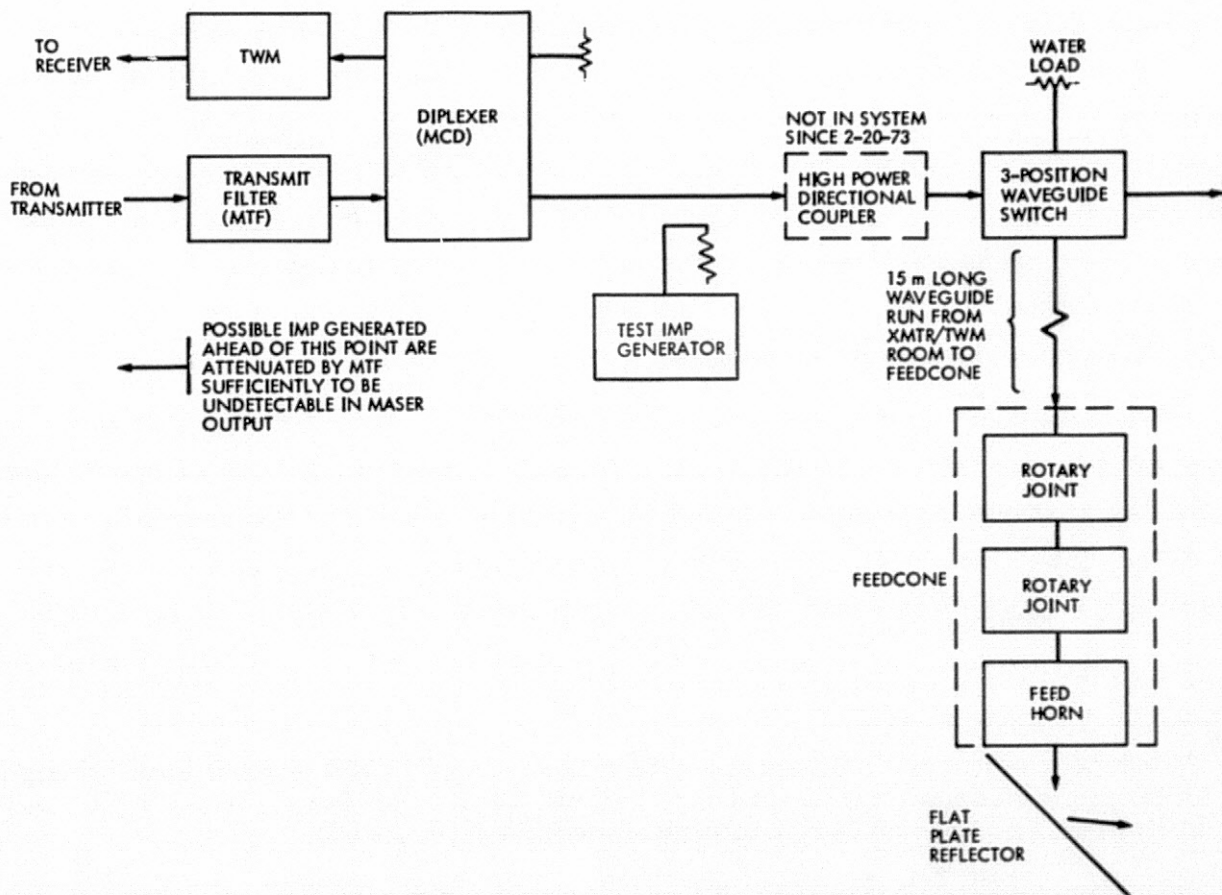


Figure 20. DSS 13 dual-carrier test system (1973)

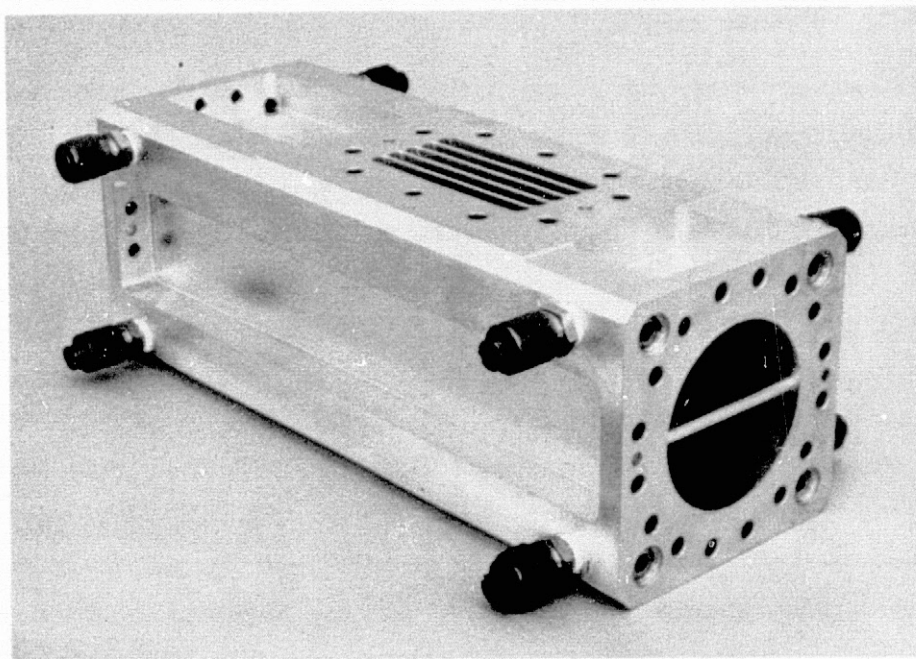


Figure 21. Orthomode transducer for SPD (PDS) feedcones

instrumentation. Another IMP test generator was developed for installation at DSS 14 (Ref. 20).

During the final months of the DSS 13 program, experiments with the application of aluminum tape, such as is used to tape panel seams on the main reflector surfaces of the antennas, indicated that the only reliable method of insuring IMP-free performance from antenna surface taping is to electrically insulate each strip of tape not only from the dish surface but also from other overlapping tape strips.¹⁹ This can be accomplished by (1) applying tape only to reliably painted metal surfaces and, (2) where two strips of tape overlap each other, separating those two layers with a thin layer of insulated tape having reliable edge margins.

At this time, crude and admittedly incomplete tests of the effectiveness of some outdoor hardware bonding methods were done. Bonded samples were exposed to reduced horn aperture field strengths while searching for NB/IMP. The key samples consisted of 6-mm-thick normally oxidized aluminum plates (roughly 50 x 150 mm) (1) lapp-joined by stainless-steel bolts/nuts/flat and lock washers and (2) butt-joined by inert gas welding (one side only). Both key samples were joined together on a discrete basis (30 mm weld or bolt centers) to test for the previously assumed sufficiency of 5 bonds per wavelength. Under no conditions could these samples be induced to fail. A control sample (one bond per wavelength) failed. Such tests are not considered totally reliable, however, due to limitations such as the presence of uncontrolled standing waves. It was concluded at the time that limited application of "skip-welding," where necessary due to practical constraints, could safely be applied in the outdoor antenna environment, for the operating conditions to be encountered.

3. Summary of DSS 13 Dual-Carrier Experience

Conclusions and recommendations based on the DSS 13 experience and applicable to an overall DSN program for noise reduction are deferred to the

¹⁹As seen in Figure 8, this was not understood during the earlier DSS 13 reconfiguration. The generally poor performance experienced (Figure 18), in the full antenna mode during wet weather, was possibly due to the large numbers of this type of deficiency.

end of this report and integrated with DSS 14 experience. This section comments only on the usefulness of the DSS 13 program, from mid-1972 until mid-1973. Following the period of background work at DSS 14, the idea of a fresh start on another station (DSS 13) did not meet with universal enthusiasm. It was recognized that significant effort would be required simply to bring DSS 13 up to the (then present) conditions, both internally and outdoors, at DSS 14. What was not then recognized were the benefits of essentially total access to the DSS 13 facilities and staff. Previous work at DSS 14 had been severely constrained because of heavy scheduling and other problems. The effort at DSS 13 was largely free from these constraints, early confirmations of some previous conclusions were reassuring, and significant initial results were available as early as December 1972. The authors suggest that without such convenient access to DSS 13, this program would probably remain incomplete as of this writing. As of July 1973, the dual-carrier noise effort at DSS 13 was terminated.

B. SUPPORTING INVESTIGATIONS

Analysis and modeling of various aspects of the dual-carrier problem were carried out, with the objective of backing the empirical field work with theory (Refs. 21-25). Of particular interest is the work by Higa and others (Ref. 23), including laboratory generation of broadband noise and intermodulation products in the receive band by means of RF-illuminated junctions of oxidized aluminum. More recently, a quantum physics model has been applied (Ref. 25), largely confirming past hypotheses of tunneling effects in the myriad metal-oxide-metal junctions on the antenna exterior.

More closely allied to the field activities was the evaluation by Kent (Ref. 26) of the degradation of telemetry and doppler data in the interference environment. With the aid of a controllable test IMP generator, a range of performance data was obtained, limited to uncoded data with near-zero doppler rates. The block diagram used at DSS 14 is shown in Figure 22. Conclusions drawn from this work are summarized in Table 6.

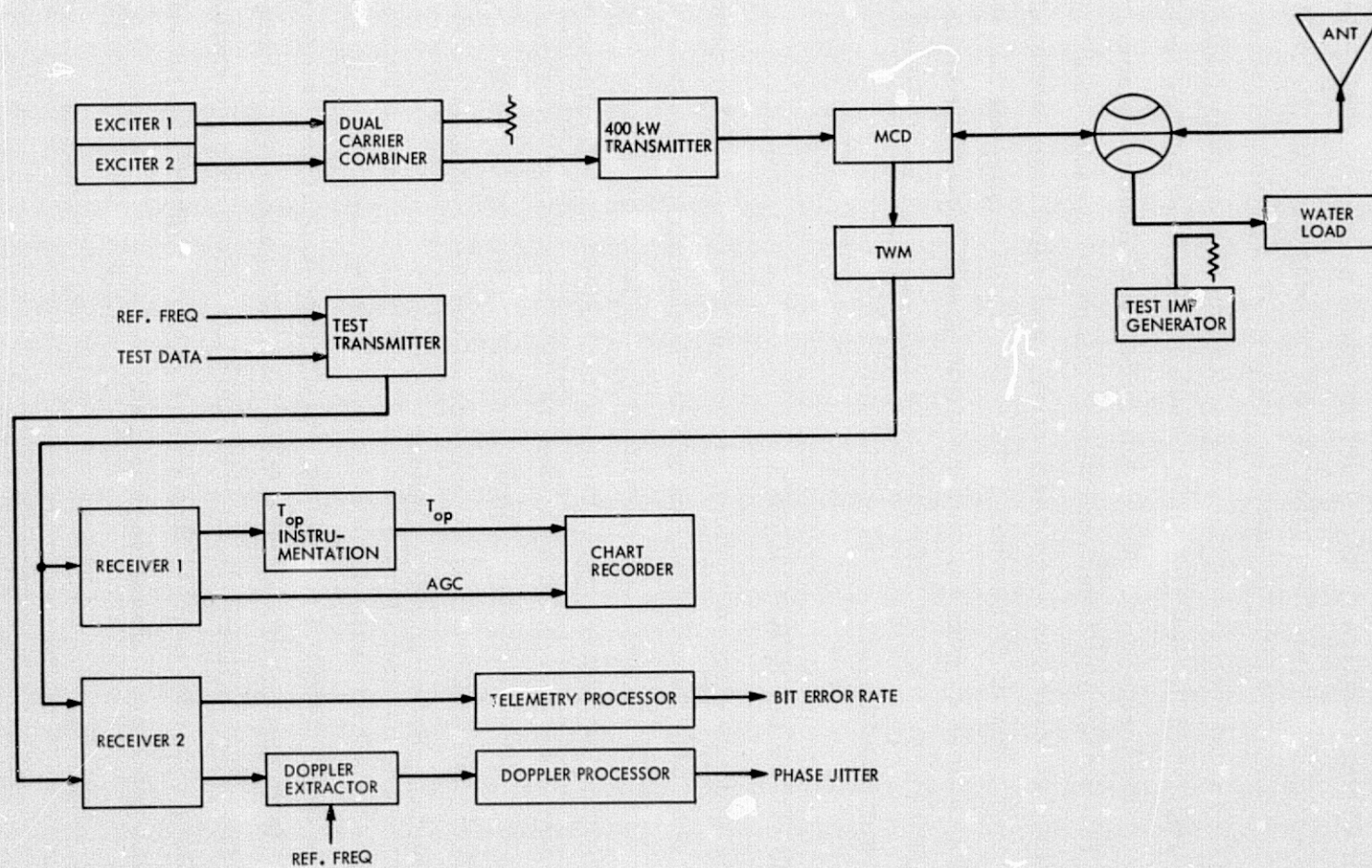


Figure 22. DSS 14 dual-carrier data degradation tests

Table 6. Dual-carrier data degradation test conclusions

-
- (1) Data degradation is directly related to the amount of IMP/noise burst activity.
 - (2) Data quality is most sensitive to IMP interfering with the carrier signal.
 - (3) In the case of telemetry, some degradation does occur where IMP interfere with the subcarrier.
 - (4) IMP activity sufficiently removed from both the carrier and sub-carrier does not affect the data quality.
 - (5) Noise burst activity, by itself, is less detrimental to data quality than is combined IMP/noise burst.
 - (6) Measurable degradation of bit error rate and doppler jitter occur whenever the carrier to mean IMP ratio is 20 dB or less, but only if it occurs on or near the carrier or subcarrier frequencies.
 - (7) Even large noise burst activity ($\Delta T_{op} \sim 100$ K) does not completely destroy data under typical operating signal level margins.
-

C. DSS 14 PROGRAM, 1973

As indicated, a return to DSS 14 was planned at the beginning of 1973. The initial scope was set at the accomplishment of whatever modifications could be made during the scheduled station downtime in February and March. In addition to a work plan for this period, tests were designed and scheduled for "before and after" interference performance during January and April-May. As of the end of May, the 10-fold improvement achieved was sufficient to uncover a level and type (spectral quality) of interference which pointed strongly to the highly illuminated feedcones with their newly installed S/X-band prototype feed hardware. This latter exterior equipment was added during the aforementioned downtime and consists of an ellipsoidal reflector atop the S-band megawatt transmit (SMT) feedcone and a dichroic plate over the Multiple X-band K-band (MXK) feedcone. It had been expected that these items with their piece-part construction (rivets, etc.) and hydraulic retraction mechanisms would prove to be troublesome in the interference sense.

Because of the then approaching Mariner Venus/Mercury 1973 (MVM'73) preparations and Pioneer 10 Jupiter encounter configuration freeze, it was

considered inadvisable to undertake any modifications to this critical equipment for the purposes of interference abatement. However, in order to capitalize on the gains already achieved, a plan was devised to remove intact the SMT and MXK feedcones, with the primary intent of evaluating the basic antenna with only the relatively simple (externally speaking) Polarization Diversity S-band (PDS) feedcone in place. Evaluation in this configuration not only indicated a further reduction in interference level but uncovered yet new clues pointing primarily to remaining problems on the quadripod apex and legs. Here again, a work plan was developed to complement an already scheduled survey and reconditioning of the main reflector. In order to maintain test configurations as orderly as possible, the reinstallation of the feedcones was delayed somewhat, with the MXK going up near the first of August and the SMT about one month later.

More test time during and after this effort would have allowed more satisfying cause-and-effect conclusions to be drawn, but thanks to the extraordinary efforts of DSN scheduling and station support, additional improvements of a hundredfold and more (30 dB since January) were obtained with sufficient control to firmly establish the reinstalled feedcones and related equipment as the limiting interference sources.

Table 7 attempts to summarize these DSS 14 activities for the purpose of establishing a time base for the discussion to follow, which will present the performance achieved at each step. The important details behind the modification summary given above will be discussed later.

1. Overview of Performance Results

Considering the completion times of Table 7 as the abscissa and the IMP mean averaged over the available test periods as the ordinate, we obtain Figure 23. As noted, all performance data are for the standard test conditions of dual 40-kW carriers at approximately 6-MHz spacing ($N = 31$).

The "pre-1973" data point is typical of observations in 1972 and perhaps earlier. The 2- to 3-dB improvement indicated in the first interval is illustrative of the concept that, for many discrete interference sources, eradication of less than a majority (assuming equal intensity for each) will result in less than 3-dB reduction in overall level. Keeping Table 7 in mind, we see a 10-dB

Table 7. DSS 14 configurations and modifications (1973)

Period	Inclusive dates	Significant elements
I	Prior to January 1973 to late January	PDS feedcone only; antenna modifications of 1969-72.
II	Late January to late May	All feedcones; antenna welding (feedcones, tricone, subreflector), waveguide component maintenance and modifications.
III	Late May to Mid-July	PDS feedcone only (MXK and SMT removed); 100-kW klystron substituted for 400-kW.
IV	Mid-July to late July	PDS feedcone only; miscellaneous antenna modifications (minor welding, temporary removal/taping of service hardware).
V	Late July to Mid-August	PDS and MXK feedcones in place; extensive welding at apex and quad legs, apex component shielding, dish tape removed.
VI	Mid-August to late August	PDS and MXK feedcones in place; more welding, new safety platform, dish retaped.
VII	Late August to Mid-September	All feedcones in place, including prototype S/X optics; full operating configuration.

reduction achieved in the next interval, which represents the addition of the S/X feedcones, downtime modifications, and refurbishment of such internal waveguide items as switches and diplexers. While some data were taken in the SMT duplex mode as well as with the PDS system, which proved helpful on a detailed diagnostic level, in general the interference performance was essentially the same with either feedcone active. For the purposes of this section, it is sufficient to consider all data as taken in the PDS mode.

As of late May, the IMP mean had not only been reduced to typically -150 dBmW (from -140 dBmW in January), it had also taken on a more stable character (i.e., less variance). Similarly, the single- and dual-carrier noise burst performance had made proportional improvements (Figure 24). As noted in the preceding section, the SMT and MXK feedcones were then removed,

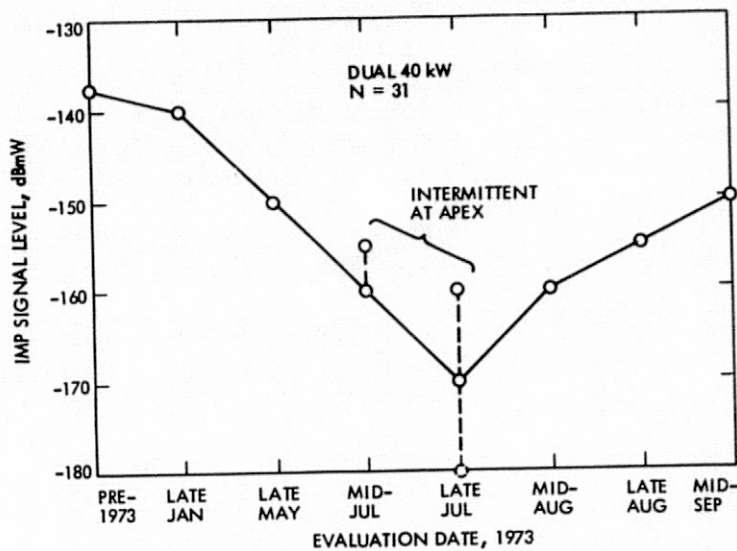


Figure 23. DSS 14 IMP performance milestones (1973)

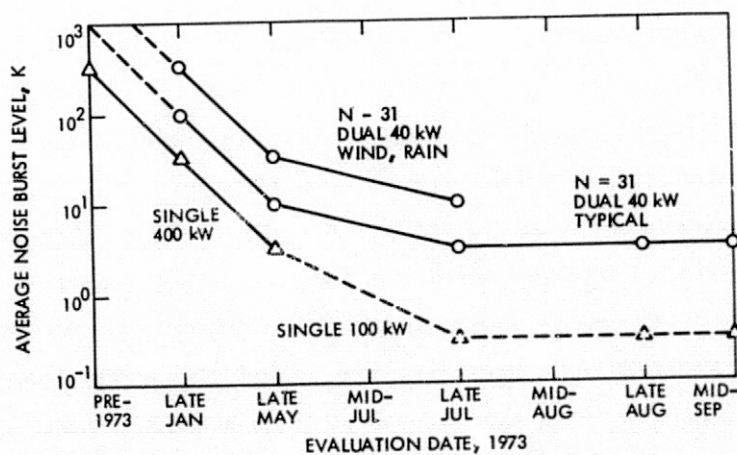


Figure 24. DSS 14 noise burst performance milestones (1973)

with an immediate 6- to 10-dB improvement. By late July, minor modifications, primarily near the surface of the main reflector, had yielded exceptionally interference-free performance: IMP means of -170 dBmW and less and NB peaks in the 3 K range, except upon mechanical agitation of the quadripod apex/subreflector assemblies. As indicated in Figure 23, this effect had first been uncovered during the prior test period, and was a primary consideration in the formulation of the August work plan (see Table 7).

Station commitments forced the reinstallation of the MXK feedcone during the August modifications, with a result that precluded the possibility of longer term observation of a probable stable interference level of -170 dBmW or less. Nonetheless, evidence in mid-August strongly indicated that the intermittence had been subdued, even though a new stable IMP level of -160 dBmW resulted from this configuration. By late August, with essentially all modifications complete, the IMP level had apparently risen to -155 dBmW. As Table 7 indicates, the main reflector had been stripped of tape and retaped during this month, but with dry weather in this period, it is believed that tape was not a factor in the August performance data.

Two apparently unrelated circumstances are of interest for this period. First, as noted in Table 7, the 400-kW klystron failed at about the time the feedcones were removed, and because spares had been temporarily consumed by other high-power transmitter programs, it was necessary to adopt the 100-kW configuration as planned for DSSs 43 and 63. In order to maintain continuity of test condition, dual 40-kW operation with the 100-kW klystron was attempted and just achieved with close monitoring of operating conditions (i.e., RF drive, beam voltage, etc.). While this mode considerably exceeded the 10 percent per carrier nominal operating power, with resulting increased level of low-order (uplink) intermodulation products in the transmitter output, special tests were conducted which indicated that the receive band IMP were probably typically generated and, if anything, this configuration would yield data on the conservative side. This transmitter configuration prevailed throughout the balance of the year.

Secondly, beginning at the mid-August tests and continuing thereafter, the prevailing IMP levels of -160, -155, and finally -150 dBmW in September became consistently more sensitive to carrier operating level. As seen in

Figure 25, a 3-dB reduction (to dual 20-kW) produced less receive band IMP in ratios approaching 30 dB (-150 to -180 dBmW). All prior experience - early 1973 as well as both DSSs 13 and 14 in 1972 - suggested a cube law effect (approximately 9 dB per 3 dB). The clear implications here are that the July and August effort not only subdued the dual 40-kW intermittent but achieved a lasting reduction of the cube law mechanism by as much as 20 to 30 dB, (referred to the 20-kW level), and that the implied interference sources associated with feedcone reinstallation are of intrinsically different type from those generally observed prior to that time. This conclusion reinforces earlier hypotheses concerning the different signatures of loose as opposed to tight RF joints and the various intermediate solid-state junctions.

Still unresolved at this time were the weather-dependent characteristics of the IMP and NB. Prior experience suggests that the August retaping of the main reflector (using latest techniques of insulation between overlapping tape junctions) will improve performance in this respect, but, as indicated by the termination of the top curve of Figure 24, there has been no opportunity to make this evaluation.

2. Detailed Modifications and Results

The first step in the 1973 program was to calculate incident RF power densities at various surface locations on the antenna. Some previous simple methods and field measurements (taken in the context of RF safety) were extended (Ref. 27). The calculations were helpful in judging relative capability of different observed surface discontinuities in different locations to generate noise. A list of power densities for selected locations is given in Table 8 for a single-carrier S-band transmitter power of 400 kW; power densities for other transmitted power levels are proportional. These power densities are also labelled at each respective location on the scale drawing of the 64-m antenna shown in Figure 26. In certain locations (QUADRIPOD LEG BASE, for example) standing-wave fields can be relied upon to produce real-world fields equal to or more than 6 dB stronger. In the cited location, DSS 13 tests verified this assumption. But in Table 8, only one location (QUADRIPOD LEG, 1 METER BELOW.....) was estimated under complex field conditions, as noted.

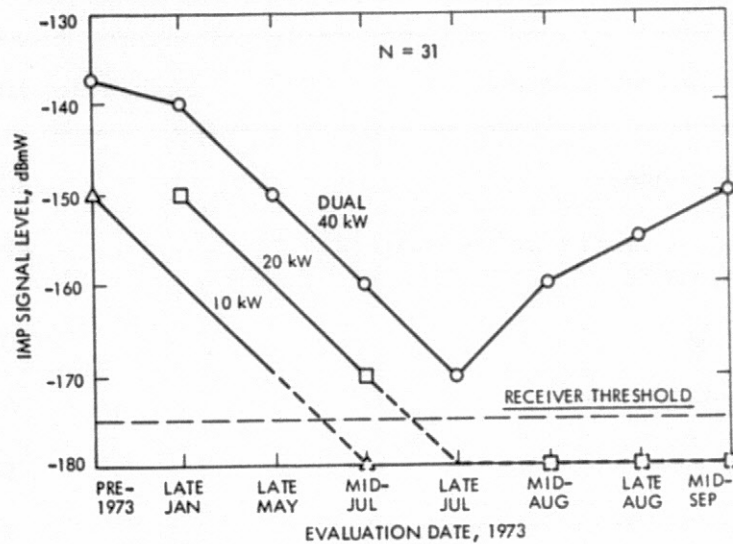


Figure 25. DSS 14 IMP performance milestones as a function of dual-carrier power (1973)

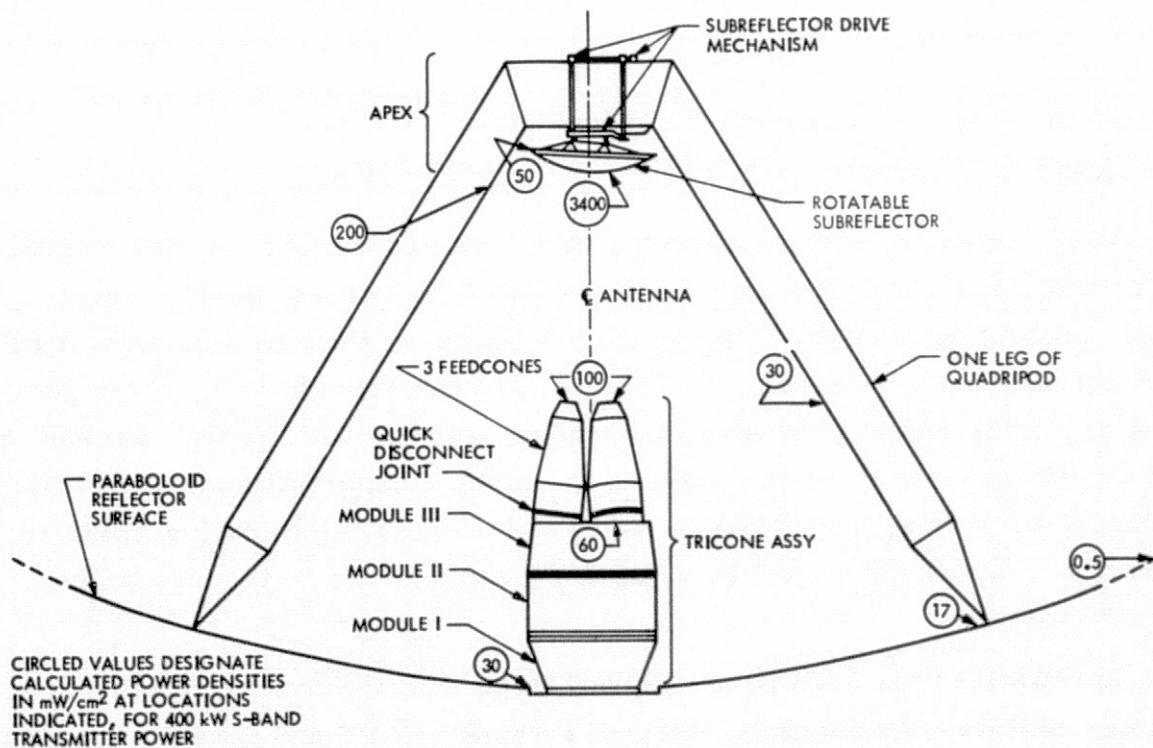


Figure 26. 64-meter antenna cross section

Table 8. Calculated RF power density at selected locations,
64-m antenna, single carrier, 400-kW transmitter, S-band

Location on antenna	Power density, mW/cm ²
Subreflector, center	3400
Quadripod leg, 1 meter below level of subreflector center	200 ^a
Feedcones, top	100
Tricone module III, top	60
Subreflector, edge	50
Main reflector surface, near module I	30 ^b
Quadripod leg, 2 meters above level of top of feedcones	30
Quadripod leg, base	17
Main reflector surface, edge	0.5

^aWorst case sum of the direct spillover ray from the feedcone added to the reflected ray from the subreflector.

^bNominal value over central region of paraboloid.

With the above information available, the program of antenna modifications was formulated. The plan, in theory, was to first correct poorly mounted, loosely contacting hardware (the worst offenders) in the zones of highest RF illumination (which, according to Table 8, are the subreflector, outer portions of the apex, top end of quad legs, feedcones, and most of the tricone) and then to gradually proceed down the scale to the more substantial numbers of firm but poorly contacting interfaces in zones of lower RF illumination (main reflector surface, lower quadripod legs, apex region directly behind center of subreflector).

In practice, the 1973 program was faced with the usual unavoidable practical constraints. As a result, desired exterior modifications were frequently not done in the order of importance, other modifications which were felt to be very important had to be delayed, and many needed changes have not been

implemented at all. Nevertheless, at the end of this program, the noise performance for the entire DSS 14 antenna system was considerably improved over original levels, as discussed in the overview.

The best way to describe the modifications that were performed to the antenna exterior is to present a chronological summary of the work. The summary that follows is divided into several time periods corresponding to those in Table 7. For each period, the work done is listed, the results of noise tests performed at the end of the work period are given, and conclusions are made. Some background items briefly mentioned in Table 4 are repeated and detailed here.

Figure 26 is helpful in locating some of the various structural components mentioned below. Baseline performance before Period I was: 20 kW, single carrier, approximate average NB: 50 K; dual carrier (limited to 1972) NB: >100 K; IMP level: -138 dBmW long-term average, with IMP peaks 20-30 dB higher.

a. Period I: 1969 to Late January 1973.

(1) Work Done. At the apex, loose floor grates were removed. Subreflector seams were covered with adhesive-backed aluminum tape and tape edges were bonded to subreflector skin with silver-bearing epoxy (cracks appeared in the tape soon after application due to subreflector minor vibration). Bolted ladder, bolted handrails, loose brackets, clamps, and tags were removed. Portions of stored hoist equipment were removed to reduce suspected vibrations.

On the steel quadripod legs, commercial grade pressed-aluminum ladders were removed and replaced with steel welded ladders. Ladder attachment points were welded. Bolted splices at upper ends of quad legs were partially welded, including tack welds on large bolt heads, washers, and nuts. A commercial grade riveted cable tray was removed. All electrical cables running up to the apex were placed inside a 200-mm-diameter conduit with all joints welded. Conduit was welded to the quad leg structure. Feedcone hoist cables, pulley blocks, and brackets were removed and temporarily stowed in a new location under the main reflector surface. A junction box was relocated below the main reflector.

All handrails and electric hoists were removed from the top of the tricone. Floodlights on module I exterior were removed and replaced with four lights on the outer rim of the dish. Loose hardware, clamps, and tags were removed.

On the main reflector surface, the width of some gaps between panels was increased to prevent tape damage. Adhesive-backed 50-mm-wide aluminum tape was applied over all gaps between panels. Metal optical target shims and targets were removed. All missing hatch covers were installed on the surface. Metal inspection tags were removed from panels. Internal transmission line work was done in this period, correcting major deficiencies as discussed previously (a detailed discussion of waveguide work will be given in a following section).

(2) Test Results. With the PDS feedcone only, 400-kW single-carrier approximate average NB was reduced to 50-70 K. Dual-carrier NB was approximately 100 K. Average IMP level was -140 dBmW. Levels remained very erratic with antenna servo drive excitation/braking and rotatable tricone subreflector actuation.

(3) Conclusions. At first glance the improvement in NB is encouraging (~10 dB) but the IMP improvement of 2 to 3 dB is not statistically significant. If one remembers the concept that, for a large number of individual noise sources, elimination of one-half of these (assuming equal intensity for each) results in only 3 dB reduction in overall level, then more improvement could not yet be expected. Many obviously poor contacts remained to be corrected. Many were still loose, but the "tight but probably oxidized" variety were prevalent.

b. Period II: Late January to Late May 1973.

(1) Work Done. At the apex, after finding that the aluminum tape repairs to the subreflector seams had fractured, the subreflector was removed to the ground and all seams in the reflector surface welded. An all-welded diffraction shield was added to the backside perimeter of the subreflector, thereby providing a reliable conductor over a radial distance of at least 2 wavelengths on the "twilight" side (Figure 27). Additional structural joints were welded that were located outside of the subreflector shadow zone (defined to be a vertical cylinder extending above the subreflector and roughly 2 meters less

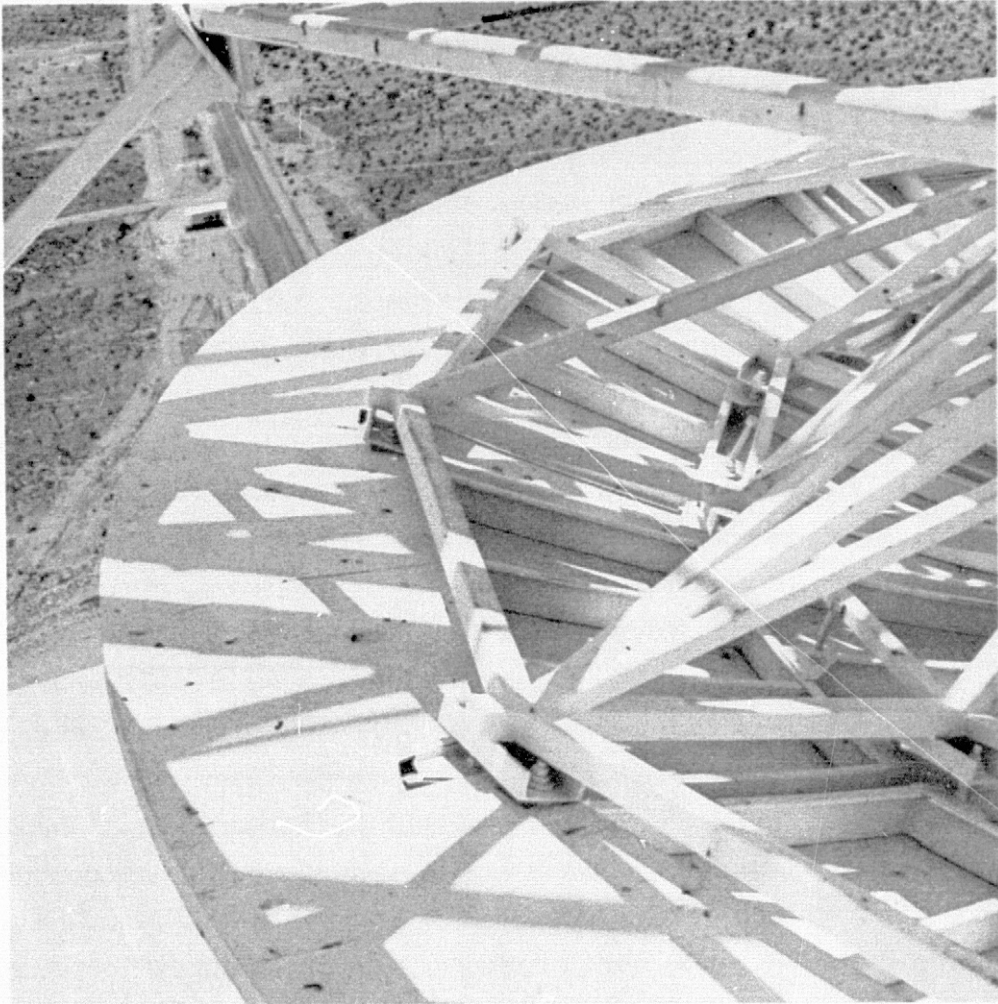


Figure 27. All-welded subreflector diffraction shield DSS 14

diameter than the subreflector) (Figure 28). Electrical cables were rerouted. The A-frame subreflector hoist fixture was removed, to further reduce vibrations.

On the quadripod legs, additional joints and seams were welded. More welding was done on the bolted splices near the top end of the quad legs. Tack welding of large bolts, nuts, and washers continued. The cable and pulley for the ground service hoist were relocated beneath the dish surface. The ground hoist control box was removed to a location under the main reflector surface.

On the tricone assembly, all exterior seams of the PDS feedcone were welded. Existing ladders, walk rings, clamps, lugs, and handrails on the PDS feedcone were removed. An all-welded ladder was installed on the PDS feedcone. MXK and SMT feedcones were installed on the top of the tricone. These feedcones were both largely welded except for their newly installed prototype S/X feed hardware. This equipment consists of an ellipsoidal reflector atop the SMT feedcone and a dichroic plate over the MXK feedcone (both shown retracted in Figure 29.) The PDS feedcone is shown with a stowed flat plate reflector in Figure 29. It was expected that the S/X feed hardware, consisting of many bolted and riveted parts, hydraulic actuation mechanisms, electrical cabling, and limit switches, would prove to be a troublesome and difficult-to-correct source of noise interference. This expectation was confirmed by later tests. All feedhorn to feedcone roof interfaces were reworked as was necessary at DSS 13. Additional bolts were added, surfaces smoothed, and light grease applied as on a waveguide flange. Seams were welded on the upper portions of tricone surfaces. Hatch details and feedcone mounting rings on the tricone roof were welded (resultant welded seams have cracks and voids which could not be corrected during the noise abatement program). On the main reflector surface, the ground service hoist air motor was relocated beneath the reflector surface.

Additional internal transmission line work was accomplished during this period, fully upgrading the DSS 14 S-band feedcones such that NB/IMP were below threshold ($>1K$, -175 dBmW) when operated with the flat plate reflector. Both feedcones had temporary soft-soldered repairs to the diplexers and transmit (receive band reject) filters and fully upgraded (lapped and greased) waveguide switch rotor parts, as will be fully discussed in Section V.

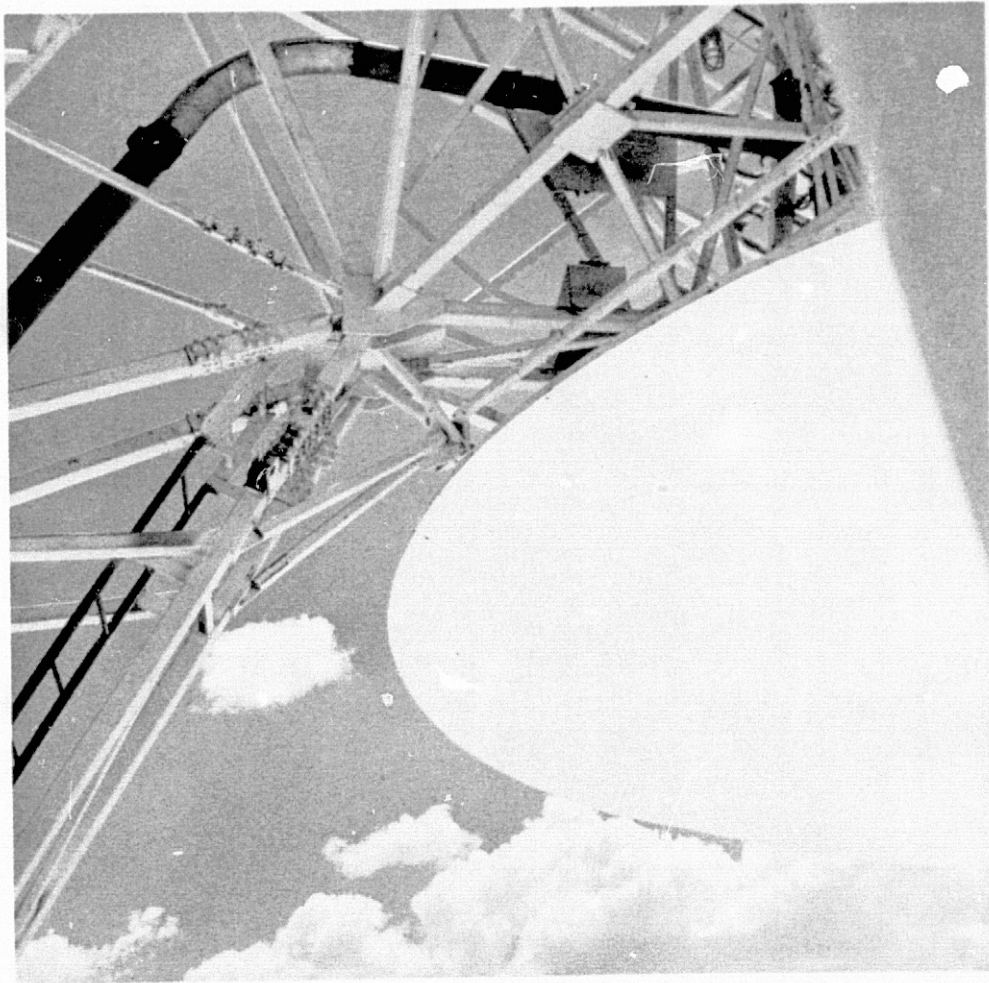


Figure 28. Subreflector shadow zone, DSS 14

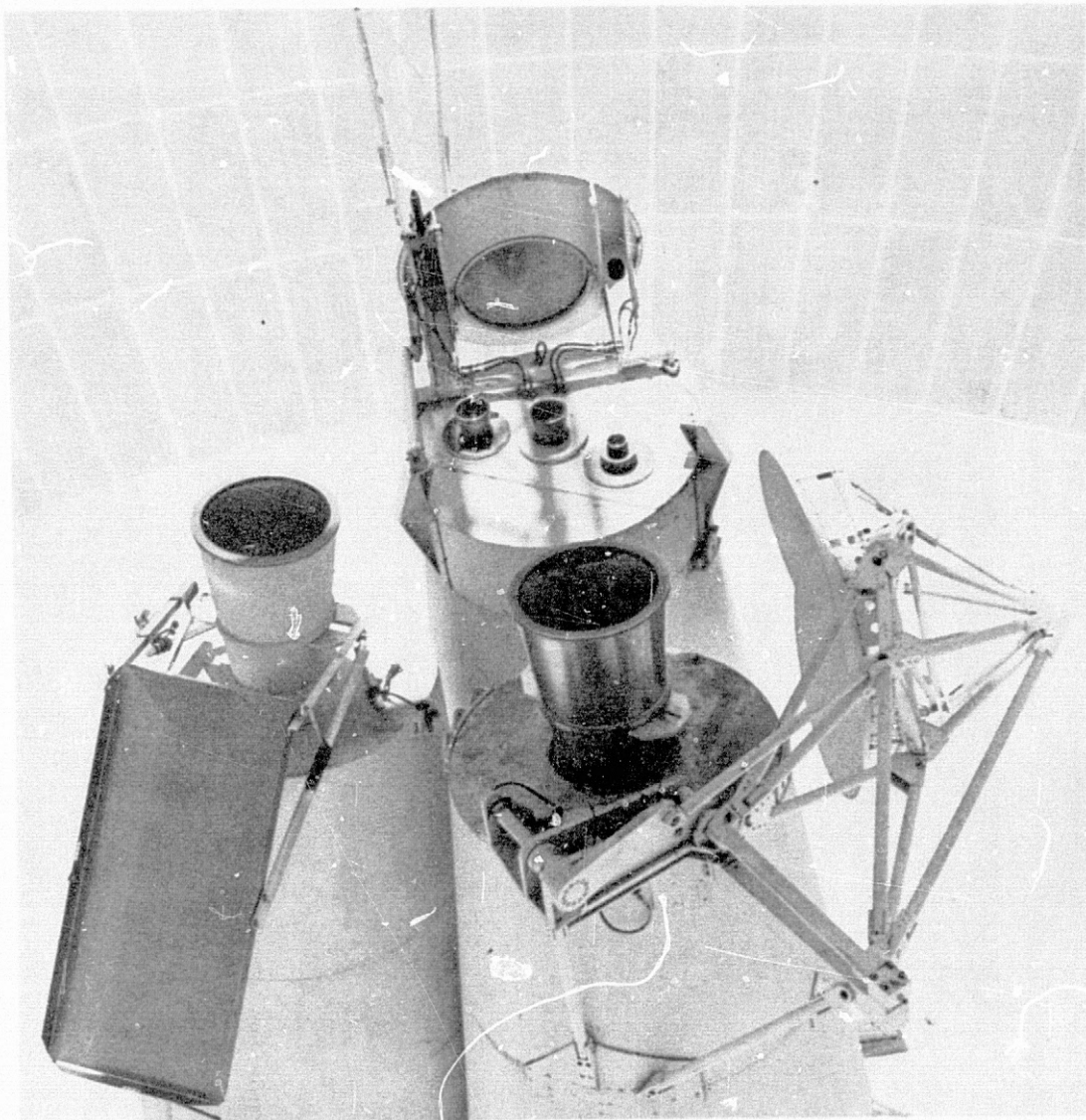


Figure 29. PDS, SMT, and MXK feedcone configuration, DSS 14

(2) Test Results. Single-carrier NB was 2-3 K. Dual-carrier NB was 10 K. IMP level was -150 dBmW. IMP level was more stable during structural excitation than in previous periods. Figure 30, parts (a) and (b), show the performance at the close of this period. These data, which include the prototype reflex/dichroic feed, illustrate the continued NB enhancement when operating with dual 40-kW carriers, compared with single 400-kW carrier. Figure 30 part (c) shows the essentially identical overall system performance duplexing with the other S-band feedcone. Each arrow in the figures represents a shock impact to the entire moving antenna structure, as mentioned earlier.

(3) Conclusions. In spite of the fact that two feedcones (MXK and SMT) were added to the antenna with their newly installed, high noise risk prototype S/X hardware, a significant improvement was achieved: 10-dB reduction in NB and IMP levels. The increased stability of the IMP suggests that very loose, poorly contacting hardware was no longer the major offender. The 10-dB factor might be interpreted as indicating that 90 percent of the initial problems had been finally abated.

c. Period III: Late May to Mid July 1973.

(1) Work Done. An opportunity became available to remove the SMT and MXK feedcones and measure antenna performance with only the PDS feedcone in place. No other modifications were performed.

(2) Test Results. Noise burst levels are not available. IMP level varied between -156 and -160 dBmW, according to mechanical vibration induced in the apex area by the subreflector drive motors.

(3) Conclusions. The removal of the two feedcones resulted in an immediate 6- to 10-dB improvement in IMP level. Vibration-sensitive noise sources which surfaced (became visible) in the apex area apparently caused the observed 4-dB IMP variations (two stable states, with/without mechanical excitation). The possibility that welds had cracked in this area was considered.

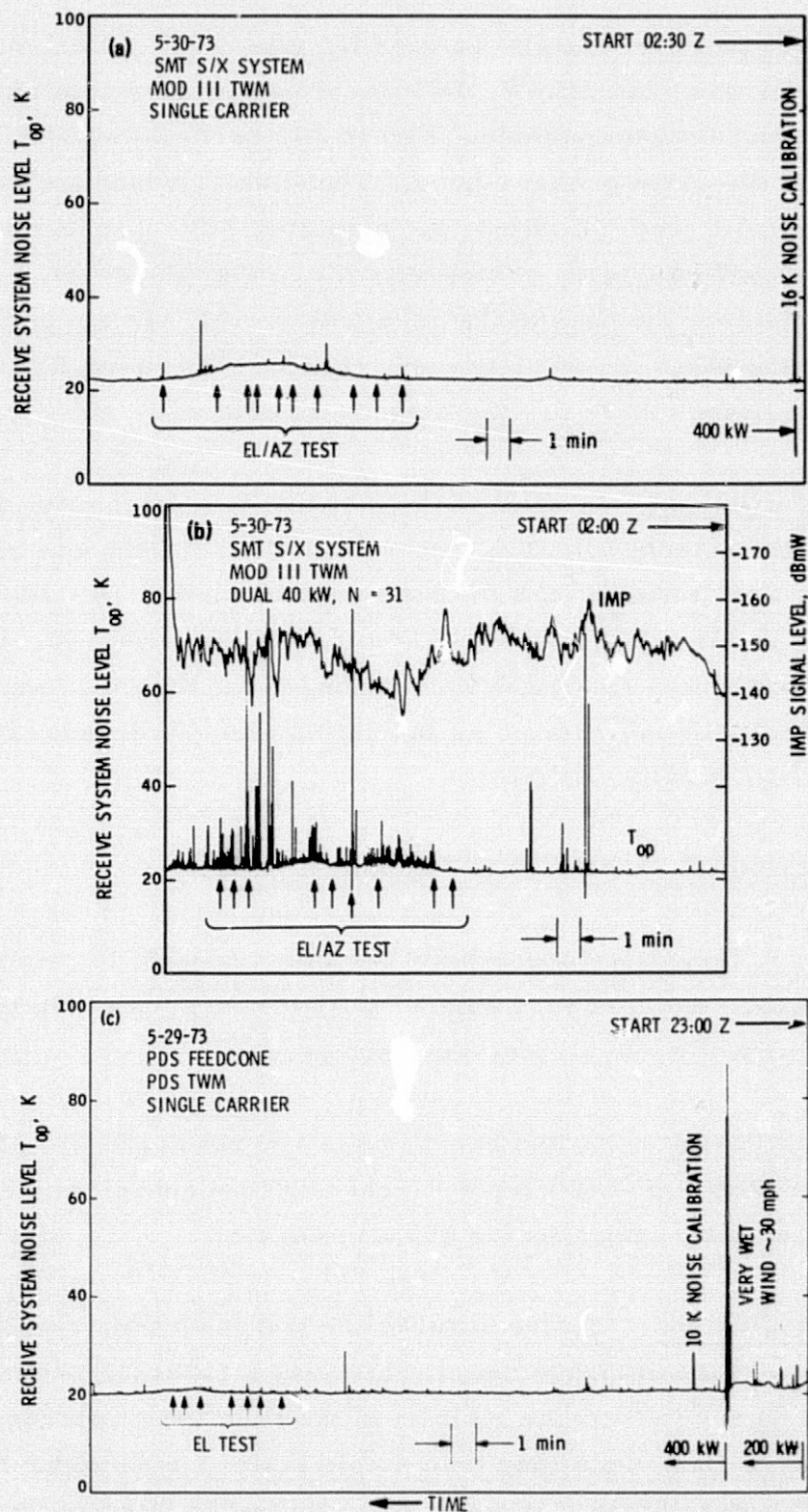


Figure 30. Representative DSS 14 noise and IMP performance (May 1973), (a) SMT feedcone with S/X optics, single carrier, (b) SMT feedcone with S/X optics, dual carrier, (c) PDS feedcone, single carrier

d. Period IV: Mid July to Late July 1973.

(1) Work Done. At the apex, the few remaining essential floor grates were welded. The telephone box and other junction boxes were tack-welded to the apex structure. Most light fixtures were removed. The remaining aircraft warning light fixture was welded and remounted near the center line of the apex.

On the quadripod legs, more joints and seams were welded, including the bolted splices near the top of the legs. Tackwelding continued on large bolts, nuts, etc. Covers around the bases of the quad legs were welded, matching edges of these covers with adjoining main reflector panels (the purpose of these covers was to completely shield the heavy steel attachment points between the quadripod leg and main reflector backup structure).

On the main reflector surface, hatch covers and other openings were temporarily taped.

On the tricone assembly, the PDS feedcone was still the only system on the antenna. More tricone seams were taped. Damaged aluminum tape over feedcone door seams and latches was replaced. (This type of tape maintenance had to be performed immediately before the RF noise test for each period, because the final design and implementation of noise-proof feedcone doors, tricone doors and hatches, and main reflector surface hatches were not yet accomplished during this phase of the noise abatement program.)

(2) Test Results. Single-carrier NB was less than 1 K. Dual-carrier NB peaks were approximately 3 K. IMP level varied from -160 dBmW to minimum detectability (less than -175 dBmW) according to mechanical vibration of apex. Internal transmission lines were verified clean by flat plate testing at this time.

(3) Conclusions. The additional welding and careful taping during this period resulted in the best noise performance achieved during the abatement program at DSS 14. Noise bursts were barely detectable. The IMP level was at -170 dBmW except when mechanical agitation was applied to the apex structure. It appears that the same microphonic noise sources seen in the previous period of work have not all been located. This significant demonstration further

supports the early view that even one uncontrolled poor joint can affect the overall performance. This suggests that finding the single remaining joint may be time-consuming, and even if found and corrected, the probability is that broken welds (particularly tack welds) or other minor damage will require on-going maintenance.

e. Period V: Late July to Mid August 1973

(1) Work Done. On the apex, much effort was applied in an attempt to squelch the intermittent source of noise interference that occurred during the last two test periods. A very complete welding of all remaining structural seams outside the defined subreflector shadow zone was done. Telephone boxes, junction boxes, and small cable hoists were relocated further inside the shadow zone. Shield covers were installed on two small cable hoists. Metal plugs with insulated attachment hardware were placed in the optical alignment ports of the subreflector to further prevent RF leakage to the backside of the subreflector. The top end of the high-pressure air line was relocated inside the shadow zone. The subreflector cable winch and associated framework were removed. Shield cans were placed over two subreflector drive motors.

On the quadripod legs, welding of all previously missed structural seams was completed.²⁰ The 200-mm conduit was remounted and more substantially welded to the quad leg structure. The air line welding was completed, bringing it up to the adopted rule of "at least one weld for every 25 mm of possibly contacting length," i. e., 5 bonds minimum per S-band wavelength.

On the tricone assembly, the MXK feedcone, including risk hardware, most unfortunately had to be reinstalled on the antenna. (Appendix A discusses the risk hardware in detail.) Further seam welding was accomplished on the tricone. Feedcone doors and latches were retaped.

On the main reflector surface, the 3500 m of aluminum tape covering the primary gaps between dish panels was removed (in preparation for applying new tape during the next period). Main reflector panel edges were further deburred to help avoid cutting through aluminum tape.

²⁰ After approximately six "passes" at welding details significant only in a noise context, located on the quad legs, we were still finding subtle defects which, on visual inspection, were an interference risk. The reader is reminded of the very-large-scale trusswork structure involved here, most of which was welded prior to erection, but important (in the noise context) details were not.

(2) Test Results. NB levels remained less than 1 K. IMP was now a steady -160 dBmW. Flat plate testing verified a clean internal system.

(3) Conclusions. Reinstallation of the MXK cone, with its dichroic plate hardware, was probably responsible for the new, stable IMP of -160 dBmW, thereby masking the intermittent apex noise source (if it still existed by this time). It was not expected that the untaped main reflector surface would present additional noise interference because of the prevailing dry weather. The stability of the IMP lends support to this view. The unfortunate feedcone reinstallation precluded obtaining a calibration of a totally untaped main reflector in the region $\text{IMP} \leq -160 \text{ dBmW}$. This desirable test would have been most helpful in a number of ways, both practical and theoretical.

f. Period VI: Mid August to Late August 1973

(1) Work Done. On the tricone assembly, welding of the tricone exterior was completed insofar as was possible. Insulation of the module 1 removable theodolite survey panels was completed. Taping over the tricone door seams and latches was accomplished using dielectric film between overlapping layers of aluminum tape. Feedcone door seams and latches were again retaped.

On the main reflector surface, new 100-mm aluminum tape was applied over all seams, gaps, hinges, latches, etc. The reflector surface was repainted in the seam zones to provide more reliable insulation. 250-mm (10-in.) squares of aluminum tape were placed over 300-mm squares of dielectric film over most tape crossover areas. Overlapping pieces of tape were insulated from each other with dielectric film. (Appendix B discusses tape application in detail.) In addition to 3500 m of primary seams, 1300 m of secondary seams (within one panel) were covered. A noise-proof (welded) safety platform at the main reflector edge was installed. On the apex, a minor amount of shielding was performed.

(2) Test Results. Noise bursts were unchanged from the last test. The IMP level increased to -155 dBmW.

(3) Conclusions. The 5-dB increase in IMP is not understood. Because past performance variations had been experienced, coupled with the restricted test time available, the statistical significance of the result is questionable.

g. Period VII: Late August to Mid September 1973

(1) Work Done. The SMT feedcone, with ellipsoidal reflector, was reinstalled on the antenna. All three feedcones were again in place. No other work was done except the now-familiar nuisance tape maintenance and other minor details.

(2) Test Results. Single-carrier noise bursts were less than 1 K as before. Dual-carrier noise bursts were still 3 K peak as before. The IMP level was now -150 dBmW.

(3) Conclusions. IMP level is now the same as at the end of Period II when all three feedcones were last on the antenna. The strong possibility is that the SMT and MXK feedcones (especially their prototype S/X feed hardware) are together the primary source of this IMP level. NB levels remain exceptionally low. It is concluded that the masking effect of IMP from presently installed hardware will not allow test visibility of possible further exterior improvements.

3. DSS 14 Program Conclusions

1. Single as well as dual carrier noise bursts at DSS 14 (as of September 1973) were diminished to insignificance, benefiting all missions. The only reservations concern the weather (as discussed above) and the presently unknown maintenance requirements (discussed or implied in an earlier section).

2. With the DSS 14 antenna and microwave equipment in the "as is" condition (as of September 1973), the dual-carrier performance at 20 kW was more than adequate to support the Viking application, as indicated in Figure 31. Note that the upper curve is taken from Figure 25 and that the worst-case Viking frequency separation offers additional margin over the nominal test conditions. Reservations are as stated in the preceding paragraph.

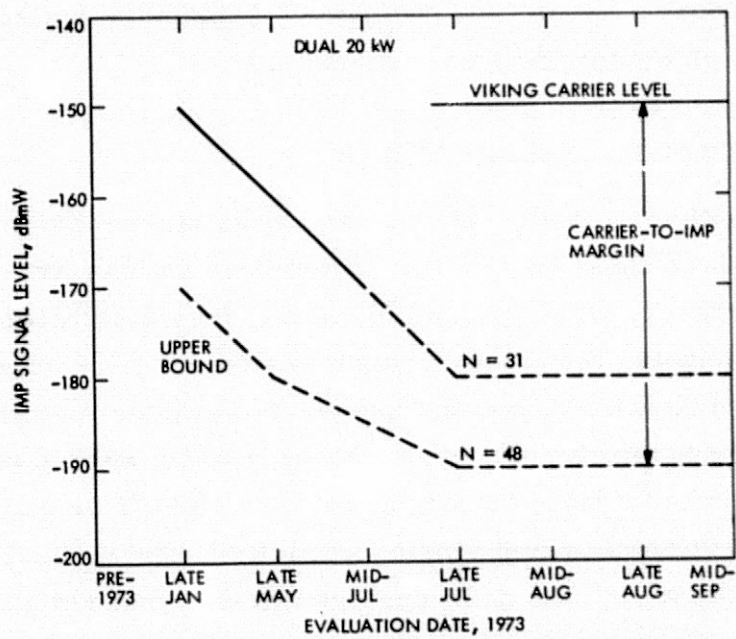


Figure 31. DSS 14 IMP performance for Viking (September 1973)

3. It is possible, at least for a short period of time, to virtually eliminate both internal and external interference on a large antenna for worst-case excitation in the DSN context.

4. It is not considered possible to maintain the ultimate implied by the preceding paragraph under normal operations for any significant period of time. It is considered possible, and even feasible, to achieve -160 to -170 dBmW IMP means and 3 K or less NB peaks for worst-case excitation, given redesign and/or elimination of some features of the present prototype S/X-band feed-cones, some mechanical details (hatches, latches, etc.) and a dedication to the requisite operational care and maintenance. (Appendix A discusses the S/X-band feed follow-on equipment improvements.)

D. APPLICATION TO DSSs 43 AND 63

The test methods, modifications, and resultant performance improvements demonstrated at both DSSs 13 and 14, incomplete as they are in a few areas (weather independence, final designs for noise-free dish hatches, some tricone module III door details, feedcone "quick disconnect" joint noise abatement, and maintenance requirements) nevertheless were complete enough by 1974 to define a recommended program for the two remaining 64-m subnet stations. It should be noted that we concentrated on single-carrier 100-kW or dual 10-kW carriers on the DSS 13 26-m antenna and single-carrier 400-kW or dual 40-kW carriers on the DSS 14 antenna; in both dual-carrier cases a frequency separation resulting in $N = 31$ ($IO = 63$) was primarily used. The remaining 64-m subnet stations will be capable of dual 10-kW carriers or a single 100-kW carrier, a less rigorous requirement by 6 dB.²¹ Further, the nominal Viking Project channels are such that the uplinks required are more closely spaced, and the receive band IMP will be of higher orders ($N \geq 48$), affording additional relief. Finally due to fiscal resource limitations, the recommended program for the 100-kW stations at this time is not as extensive as for DSS 14.

²¹ However, 6 dB has been demonstrated to be an uncomfortable margin on which engineering decisions can be made regarding noise abatement.

One fundamental decision which deserves discussion was necessary, on the basis of design, risk and time resources. The subreflector at DSS 14, although noise abated, was in fact degraded by welding with respect to surface tolerance, to the extent of 0.5 dB gain loss at X-band (Ref. 28). The fundamental decision to not weld the DSS 43/63 subreflectors at this time (if ever) may limit the noise performance at those antennas. Present construction methods lead to fractured tape, which is a first-order noise source in a critical high power density zone. The recommended method (insulated tape first, followed by metallic tape with semiflexible backside joint caulking for vibration damping) may alleviate the fracturing to some extent (Appendix B). This accepted risk approach must be understood by those concerned.

Remaining recommendations for 100 kW stations generally follow the DSS 13/14 approach of giving first priority to loose hardware in high power density zones. In this regard, the reader's attention is drawn to the second and third most important locations shown in Table 8. The quadripod legs, in the upper regions, are very important (but not overly difficult to correct). The feedcone tops are slightly more difficult. Although the simultaneous S/X band reflex-dichroic feed system follow-on units and recently completed X-band feedcones are noise-proofed, the older overseas S-band feedcones are not. It will be necessary to either remove the feedhorns and prepare the interfaces as discussed (waveguide-like flange preparation, 5 bolts per wavelength, corrosion protection, etc.) or accept a welded joint at the interface. This is a task which requires station downtime (a rare event in the heavily committed 64-m network).

V. SUMMARY

A. CAUSES OF INTERFERENCE

Both NB and high-level (approximately > -150 dBmW) typically unstable high-order IMP, as observed in the DSN, are believed due to RF microdischarge (arcing) found in both guided/unguided transmission lines/reflectors. Early speculation backed up with later theory (Ref. 25) of metal-oxide-metal (MOM) junctions strongly suggests that lower level, relatively steady IMP (-160 , -170 dBmW) may be due to those solid junctions. Of importance, however, is the continued observation that the solid junction phenomena are

detectable only outdoors, since flat plate reflector tests reliably demonstrate that solid junctions within the waveguide system, if active, are collectively at or below -175 dBmW.²² This is a very interesting result; the current densities in waveguide are orders of magnitude greater than on the reflector surfaces. It should be recalled that most of the waveguide and flanges used in these programs were copper/copper alloy, while the outdoor reflectors are 100% aluminum (except for steel quadripod legs). Further, the theory of metal-oxide-metal junctions indicates that very large numbers are required for detectability in the DSN (Ref. 25).

The larger arc discharges seen through January 1973 appear to be the typical result of heretofore uncontrolled mechanical connections on large outdoor structures, with significant contribution due to faulty transmission line component mechanical design, fabrication, installation, and insufficient maintenance. The outdoor problem is also known in other technologies. The bibliography lists a number of interesting papers in this connection. Microdischarge associated with microfractures and loose metal chips within the waveguide system normally passes unnoticed in transmit or receive-only antenna systems (including JPL developmental planetary radars) but is outstandingly visible in the diplexed systems.

We are confident that detectable high-order intermodulation products do not originate within the normal transmitter system itself, at least for reasonably installed and maintained equipment. Low-order intermodulation, for example third-order IMP, is characteristic of DSN transmitter systems (Figure 32). Conversion efficiency in Figure 32 is simply power output (at the third-order IMP frequency) compared with power input (of one of the balanced fundamentals). Not surprisingly, a coaxial connector is at least 60-dB more efficient in generating third order intermodulation than a good waveguide flange. But because the DSN dual-carrier system combines the signals at the drive

²² This result must be qualified as applicable only to the DSN non-monopulse tracking (64-m class antenna) feeds, not necessarily applicable to equipment as installed in the older 26-m networks.

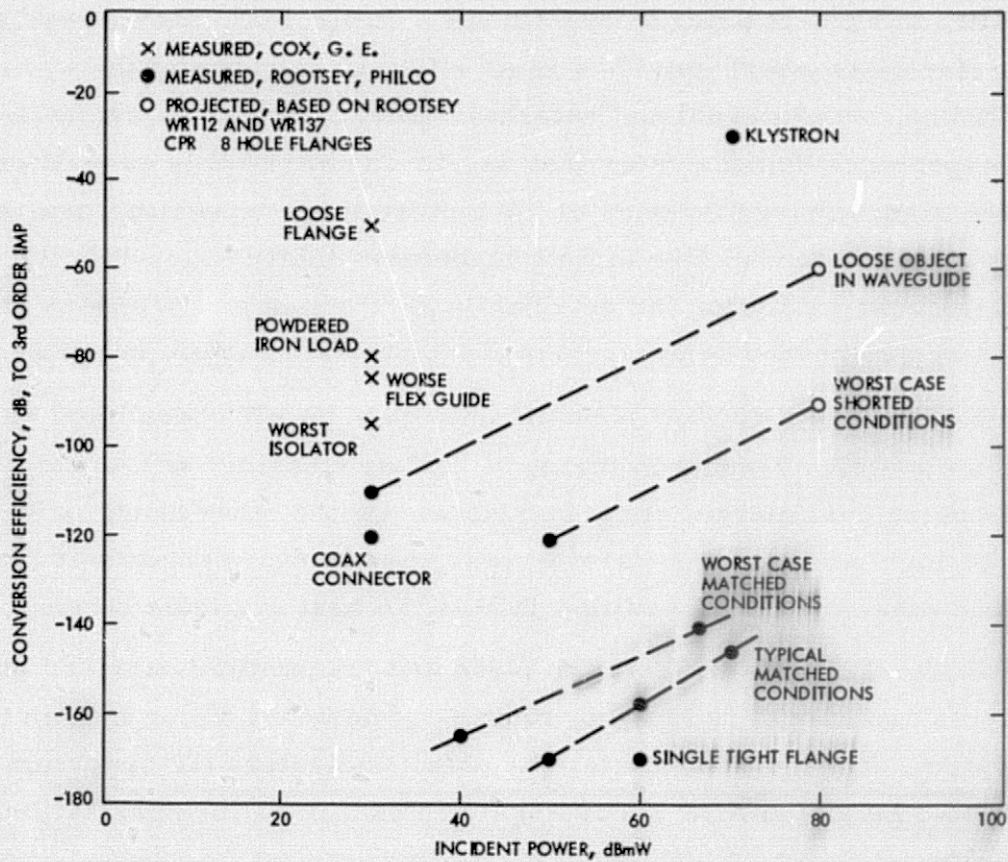


Figure 32. Third-order IMP generation

level and throughputs the pair using a single klystron amplifier, low-order performance is dominated by the klystron.²³

B. TEST EQUIPMENT AND PROCEDURES

It has been suggested that waveguide system "burn-in" maintenance be conducted periodically using a power level significantly above the operating level, even recognizing that system operating level is generally dictated to be the maximum available level (Ref. 20). Experience at DSS 13 confirms the desirability of burn-in prior to system use. In the DSN, high-power single- and dual-carrier tests would provide a most efficient measure of the system noise susceptibility, both internal and external. Where only NB is available for monitoring, experience demonstrates that day-to-day variability as well as minimum detectable signal characteristics of the indicator are unsatisfactory, except in detecting gross failures. Use of both techniques (highest possible RF power level and dual-carrier excitation for detectability), for test and pre-pass stress purposes, is recommended to preserve and monitor the system integrity.

For example, a 100-kW burn-in prior to a 10-kW operational pass is considered completely adequate in terms of "RF processing" and would provide a reliable operational margin of performance. On the other hand, prior to a dual-carrier or high power single-carrier pass, use of dual carriers at the maximum level while measuring any resulting IMP is the best available strategy.

With the flat plate reflector in place and transmitter carriers on, the following tests are helpful in locating sources of detected NB or IMP in the waveguide system. During these tests, the output indicators (IF spectrum analyzer, system noise level and AGC recordings) are examined for correlation with the test activity.

1. A portable RF probe may be used to search for leakage from waveguide flanges, tuning screws, etc. Leakage can indicate possible broken flanges,

²³The abatement measures taken thus far in the DSN might be woefully inadequate for systems designed such that low-order IMP (e.g., third-order) falls within the receive band (even for systems employing separate final amplifiers). A review of the bibliography will indicate the seriousness of this problem. Possible future higher frequency DSN uplink planning will not be complete without considerations of this kind.

untightened flange bolts and bent or corroded flanges. All of these conditions have demonstrated the ability to produce NB and/or IMP. Such conditions are not only troublesome but hazardous.

2. Judicious hammering and prying (using wooden, plastic, or other soft-edged implements) can be performed along waveguide runs to look for any correlation between the mechanical disturbance and the output indications, as before. This has been a very effective method for locating noise sources. Most sources have been found to be sensitive to mechanical movement.

3. Waveguide switches and polarizers can be actuated to look for correlation with the receiver outputs. Loose metallic particles caught in the choke joints of these devices have been located using this test.

4. An interesting test configuration that has proved useful in the past utilizes the orthomode junction. This device causes an incoming signal from the feed-horn to be split into two parts; the right-hand circular polarized component is delivered to one output port, and the left-hand circular polarized component is delivered to the other port (or alternatively, two orthogonal linear polarizations can be selected). Additionally, the isolation from one output port to the other is approximately 25 dB. These characteristics may be helpful in locating a source of noise that is near the diplexer as follows: If a noise source exists in the diplexer or in the waveguide system between the diplexer and the orthomode, the received noise level into that receiver should be 25 dB higher than the level detected in the orthogonal receiver (the difference should be exactly equal to the isolation across the orthomode). On the other hand, if the noise source is in the remaining feed system or external antenna, the difference between the two receiver levels may be much less (depending on the distribution of polarizations in the observed noise interference). Of course, noise generated in the orthomode itself cannot be ruled out in either case. However, the possibility of this occurring is considered to be slight owing to the low risk nature of the mechanical construction.

5. Another test that has proved helpful makes use of the fact that DSN diplexers have very small receive band loss in the diagonal direction (as discussed previously) while presenting approximately 30 dB isolation (at 2290-2300 MHz) in the other signal paths. Therefore, by comparing noise strength at the TWM port versus the normally terminated port, a determination can be made as to which high-power port noise is coming from. Of course, the possibility that noise is originating in the diplexer itself cannot be ruled out for this test result.

At DSS 13, a comparison of noise interference levels in the two lower ports of the diplexer showed a difference of only 0- to 10 dB, instead of the 30-dB difference expected if the noise was entering one or the other high power ports as described above. Therefore, it was concluded that perhaps a single source of noise was located inside the high-power portion of the diplexer itself. This proved to be the case.

6. If these methods fail to satisfactorily locate all sources, the next step is to reduce the extent of the internal waveguide under test by using a high-power water load as a termination instead of the feedhorn/flat plate reflector (one disadvantage of this alternate approach is the resultant high system noise temperature of 300 K). The system can be switched to a water load, thereby eliminating the feed system and other waveguide parts from the system under test. In desperate situations, the waveguide can be disassembled at any point on the antenna side of the diplexer and the water load inserted for a noise test. It must be kept in mind that the water load itself must have been previously demonstrated to have acceptably low noise levels. When increased receiver sensitivity is needed, a receive frequency band stop filter (the MTF filter) placed ahead of the water load will reduce equivalent system noise temperature because, as described earlier, it terminates the maser amplifier with a reactance.

This list is not intended to give the impression that all noise sources observed in the DSSs 13 and 14 waveguide systems were located by orderly applications of the test suggestions given here. Such was occasionally the case, but when one had two or more noise sources emitted intermittently or in unison during the same test periods, the troubleshooting exercise became very difficult, since apparently conflicting results were obtained. In one

instance, at DSS 13, for example, three discrete sources in different locations were simultaneously present. Each was eventually identified but only after extensive trial and error troubleshooting.

Locating noise from outdoor sources is considerably more difficult. Although some use was made of mechanical excitation of main reflector panels from below (a broomstick works well), and in one ground test a mechanical shaker was used (an offset weight on a small ac motor), extensive climbing on the backside exposed reflector framework is not recommended. Rotating the 64-m tricone subreflector to different feed positions has been very effective in showing the intermittent character of initial taping fractures and other deficiencies.²⁴ Similarly, rotating the entire antenna in azimuth and/or elevation at approximately 0.1 deg/sec with sudden application of servo drive brakes is very effective. When done at zenith (azimuth drives), a torsional motion is imparted to the quadripod. When done at lower elevation angles (say 20 deg), again in azimuth, a distinctly different vibrational mode is excited. In early tests at DSS 14, with 400-kW single carrier, the visible motion of the damped quadripod oscillations were fully correlated with audible noise (from the receive system noise stripchart recorder saturating on noise bursts at the upper mechanical pen stop). Close visual inspection by an experienced observer remains the best method of locating outdoor sources.

C. WAVEGUIDE CONSTRUCTION PRACTICE

During the noise abatement program, it became apparent through repeated experience that certain fabrication, assembly and inspection procedures for waveguide components are acceptable for DSN use and others are not.

1. Waveguide internal surfaces must be clean and free of cracks (except for the obvious case of carefully prepared waveguide flange interfaces). It is difficult to define "clean." As a general rule, with copper parts, we use these

²⁴This test should be done only at zenith, with appropriate warning to site personnel. Some additional spillover (past the rim of the main reflector) results when the system is not properly focussed on the active feedcone.

criteria: The part should be designed so as to allow mild acid cleaning (no capillaries nor other fluid traps). Acid cleaning must be followed by substantial flushing with clean tap water, with a final hot (150°F) distilled water rinse preferred. Mild application of heat (250°F) is desirable but apparently not necessary for thorough drying of most parts. Application of a final protective film, (Irridite, Metcote No. 7)²⁵ substantially reduces further oxidation. Although this process results in a bright clean surface, such cleanliness of appearance is necessary primarily to (1) assure uniformity and (2) provide ease of visual inspection. Actually, many proven parts have aged to a surface appearance grossly clean but quite dark. Such mild oxides are found unimportant, provided they do not occur on flange interfaces.

An interesting problem came up with regard to extruded copper waveguide. At the mill, loose copper chips are occasionally pressed into the interior surface of the waveguide during the extrusion process. The chips, having been work-hardened, press readily into the softer surface. Under repeated thermal cycling in a high-power waveguide system, a millimeter-by-centimeter-sized chip inside a straight section of waveguide curled up from the surface and caused massive arcing with resultant high noise bursts being observed.²⁶

Figure 33 shows one such long waveguide after longitudinal parting (including noticeable evidence of unacceptable cleaning procedure). The indicated areas are magnified in Figures 34 and 35. In Figure 34, the work-hardened massive chip is seen partially noncontacting the waveguide wall (dark shadow). In Figure 35, a second chip location is seen. Lighting may cause a positive appearance of this defect; actually, the chip material is gone and the figure shows the resultant depression. Internal visual inspection of new waveguide, possibly under the application of mild thermal cycling (oxyacetylene or propane torch), is recommended.

²⁵ Metcote No. 7 is a product of Allied Kelite Div., Richardson Chemical Co., Federal Code 99442. (30-sec maximum immersion.)

²⁶ Visual inspection, achievable only after the part had cooled, did not immediately reveal the chip. This was in part due to the long length of the waveguide (2-3 meters), but further, this chip behaved in a bimetallic manner, and retreated flush with the surface upon cooling. Subsequent checking of other waveguides revealed several additional such chips.

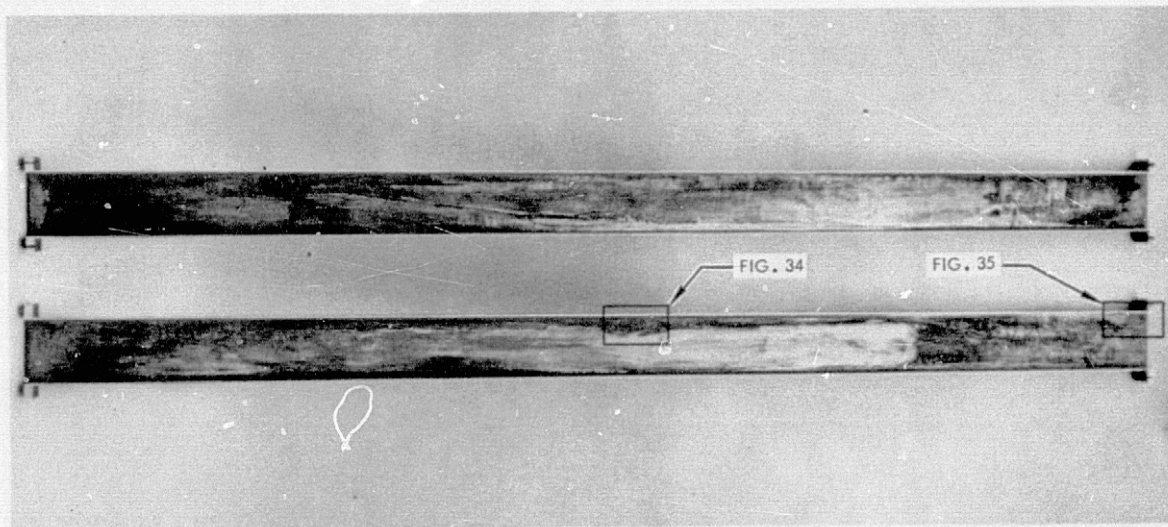


Figure 33. Long waveguide, longitudinally parted with closeup areas



Figure 34. Closeup of imbedded chip

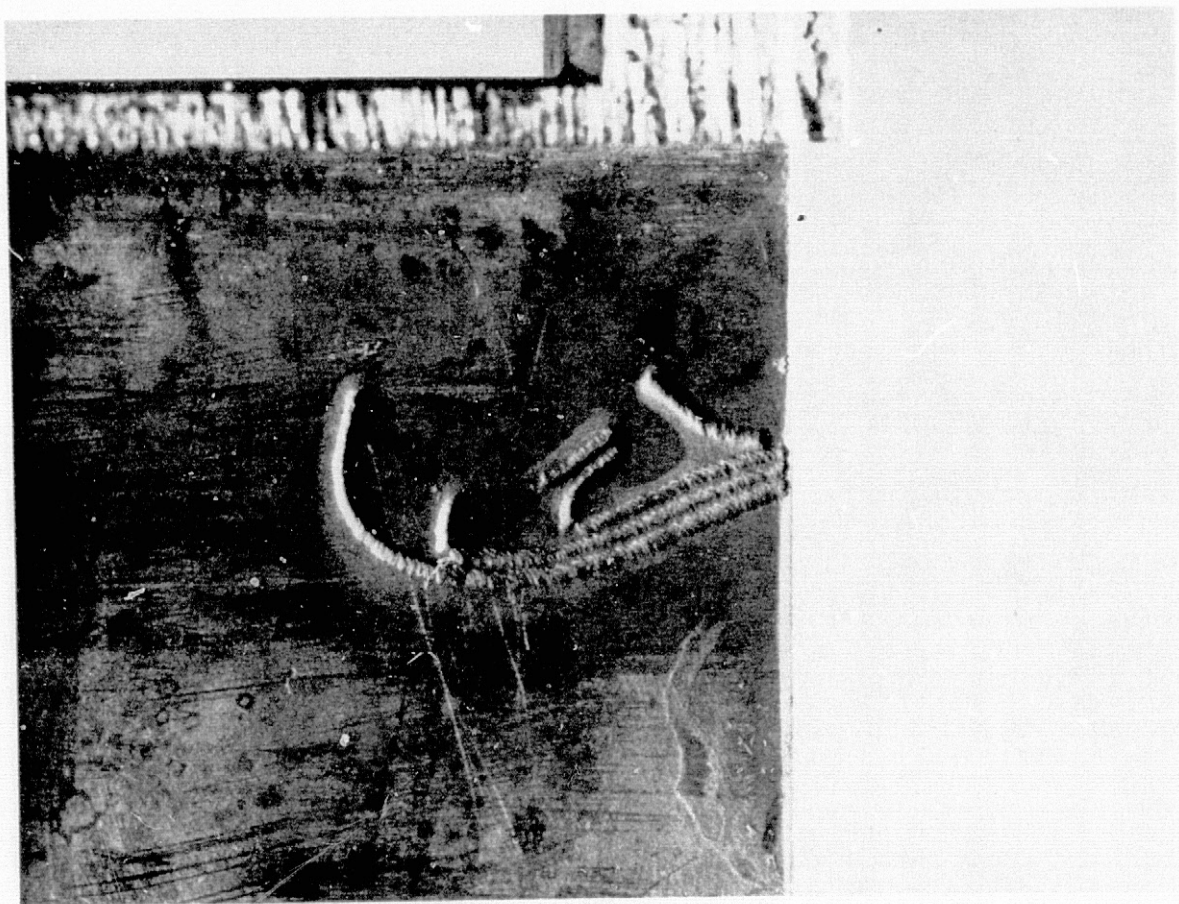


Figure 35. Closeup of chip impression

2. Waveguide components for critical high power service should not be designed or fabricated in such a way as to prevent close internal inspection. Also, sections too long for reliable visual inspection for microcracks and pressed-in chips are not recommended. Dye penetrant and borescopes have been helpful in locating cracks.

3. Waveguide flanges must be carefully deburred, lapped to a 400 grit finish on a surface table, cleaned and rinsed with a residue-free solvent, lightly greased, and assembled according to the DSN standard preparation and installation procedure for WR-430 waveguide assemblies (Ref. 18). Additionally, it is important that the application of grease occur within a few minutes after the completion of lapping, cleaning, and rinsing. Paint, anywhere on the flange exterior is risky. The high incidence of paint chips within waveguides seen on this program suggests that some chips find their way between mated flanges.

The DSS 13/14 noise abatement programs were very unforgiving of carelessly prepared and/or assembled waveguide flanges. Pulling waveguides together by use of flange bolts is the easiest way to distort an otherwise flat flange pair. Use of shims is recommended (see 5 below). Forcing dowel pins is another dangerous practice. Many distorted flanges (in the areas near the pin holes) were seen. Pins must be a free fit, never forced.

4. Waveguide switch rotor assemblies (rotor body and plate) must be prepared and assembled with the same procedure provided for waveguide flanges. Waveguide switch stators should be free of paint anywhere in the region of the flange connection, and machined relief zones are recommended to avoid lapping needlessly oversized flange surfaces.

5. Waveguide flanges must be subjected to very minimal mechanical stress when being bolted to a mating flange. Minor warping of a flange during assembly has been shown to result in degraded noise performance. Of prime importance is the design of mechanical support layouts which avoid stress buildup in complex waveguide assemblies both during the assembly and later operational stages. Machined waveguide cross-section shims must be installed as required to achieve proper waveguide fits even though they represent a doubling of the number of flange interfaces (in the limit).

6. Extreme care must be exercised to prevent metallic particles or other foreign material from entering the waveguide system during assembly or disassembly of any part in the system. In particular, the existence of a single small chip between the rotor and stator of a waveguide switch, or in the choke gap of a rotary joint, is disastrous to noise performance and may destroy the component for further service. Corrugated horn slots must be free of trapped chips and debris (easier said than accomplished). In general, loose metallic particles within the waveguide may be likened to microcracks, inasmuch as high fields may exist between the particulate and the waveguide wall. Late in the program, the use of aluminum oxide paper, for flange lapping, was encouraged for this reason.

7. Hydrogen oven brazing, electric discharge machining, and silver soldering are the preferred methods of assembling waveguide components. However, these processes are not without pitfalls: visual inspection must be carefully performed to insure that small cracks or voids do not exist in brazed seams. (Of course, complete visual inspection of any waveguide component is a requirement to insure that no cracks or voids exist, as mentioned.) Also, soldering flux residues remaining in the component after cleaning operations will invariably cause corrosion that may eventually result in noise generation. Extreme care must be exercised during cleaning and inspection to insure that all traces of contamination have been removed.

8. Dip brazing of aluminum parts has been demonstrated to be an unacceptable method for assembling waveguide components (including waveguide switch rotors), in our experience. However, welding (tungsten inert gas or consumable electrode in inert gas) and/or simple bolting (according to standard waveguide flange preparation and assembly procedures) are generally found acceptable.

9. Soft solder is an acceptable temporary bonding method only for test filling of cracks around tuning screws, matching posts, etc., where there are no mechanical stresses nor high temperatures.

10. The use of electroforming and casting of waveguide components for dual-carrier service must remain an open question. Stress cracking with electroformed parts was a general problem; pits, bubbles and general porosity in castings are suspect but were not identified in the program.

The above list is not complete, but it demonstrates the high degree of sensible, real-world quality control which must be applied if a waveguide system is to maintain acceptable noise performance during diplexed operation. Despite use of generally conservative construction practice, including use of all cover flanges 15 mm (5/8 in.) thick and 3.2 mm (1/8 in.) thick, WR430 waveguides of copper alloy/copper materials, many problems nevertheless arose. In addition to the above general considerations, specific experiences regarding individual DSN components shown in Figures 6 and 20 will be related below.

D. INDIVIDUAL WAVEGUIDE COMPONENTS

1. Transmitter

Transmitter-generated single-carrier noise bursts could possibly be caused by poor electrical connections at any point in the exciter chain, amplifiers, or power supplies. In addition, dual-carrier operation results in IMP caused by nonlinearities in transmitter subassemblies that are operating simultaneously at both frequencies. Also, the lengthy output waveguide run, which includes filters, switches, and directional coupler, presents potential candidates for noise generation. Since the transmitter and the output waveguide run are not required to pass receive band frequencies, the simplest and most reliable means of preventing receive band NB/IMP from reaching the diplexer is to install the receive band-stop filter, termed MTF, as close to the diplexer as possible. Figure 36 shows the PDS feedcone interior. The MTF filter is within the conical stand in the lower left of the figure. Four flange interfaces are seen before entry to the diplexer in the upper right of Figure 36 is made.²⁷ While these interfaces might be reduced, the risk of constructing an uninspectable part must be considered. The full assembly of the orthomode is seen in this figure, as well as the high power end of the diplexer.

Despite use of the bandstop filter, the quality of the transmitter waveguide system must be high. The 120-dB rejection of the MTF is not sufficient to protect the receiving system from noise associated with massive arcing. Particularly in the case of series-type arc (as across a waveguide flange interface, for example), where line impedance is affected little or not at all,

²⁷ A later modification to the PDS system as well as the follow-on SPD units places a waveguide switch between the orthomode and the waveguide elbow entering the diplexer. This switch was recognized as an additional noise risk; at least one unit failed.

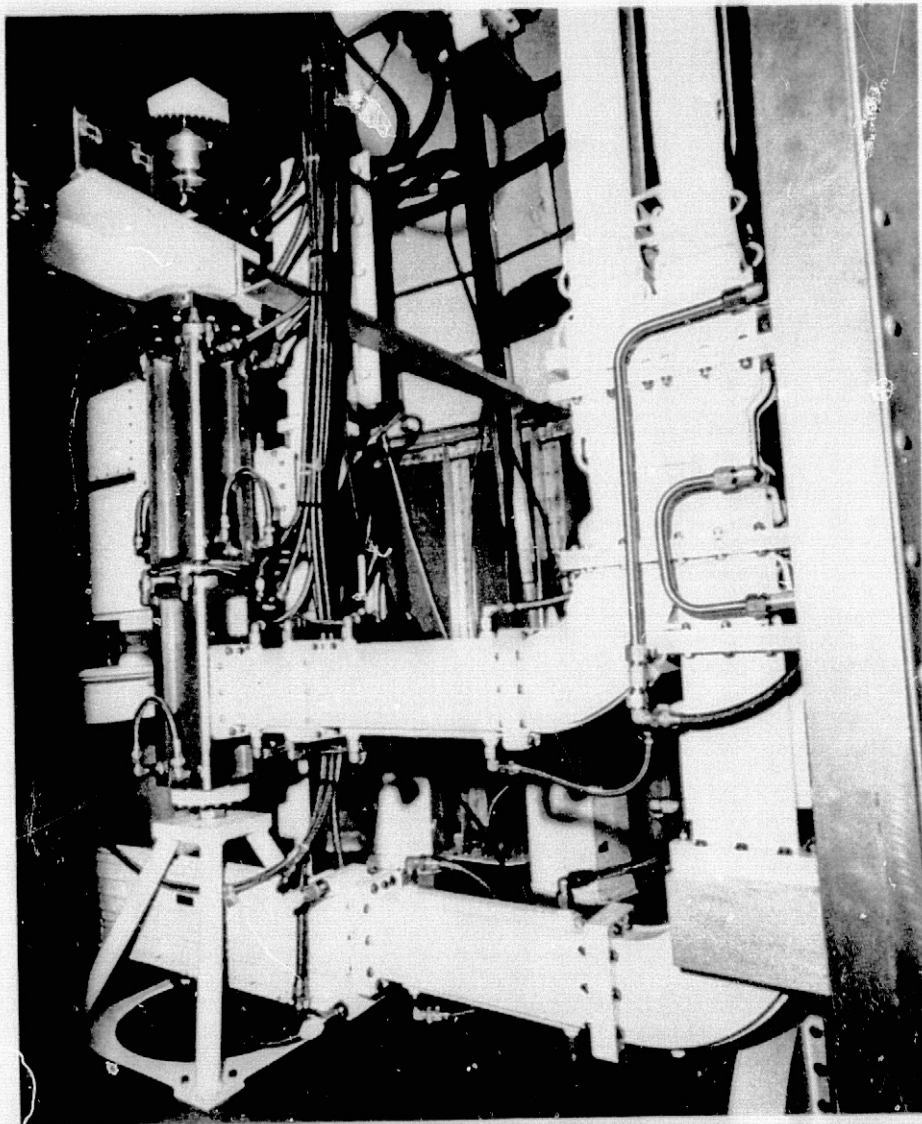


Figure 36. PDS feedcone interior

transmitter protection devices will typically not detect an arc of this kind, and it will continue to generate noise interference.

2. High-Power Directional Coupler

High-power directional couplers (the type used in the 400-kW transmitter cabinets to monitor forward and reflected power) are not included in the shared waveguide portions of present (or planned) waveguide systems for either 26- or 64-m antennas. However, a coupler was installed in the DSS 13 system, as shown in Figures 6 and 20, and the late failure of this component during dual-carrier testing is of general interest.

In February, 1973, the coupler was found to generate severe noise bursts and IMP during hammer testing. The coupler was removed, and inspection revealed the probable source of noise to be a fabrication joint in the internal waveguide surface which had not been silver-soldered. In addition to being contrary to reasonable waveguide fabrication techniques, it is felt that this construction constitutes a safety hazard because major arcing might occur across the internal crack and melt or otherwise damage the unit. The previous acceptable performance of the item points out the obvious desirability of a little "tire-kicking" while initially testing hardware. In this case a deficient item had remained dormant for many months, for reasons we do not understand.

3. Diplexers (MCD)

By late January 1973 the steady -160 dBmW problem at DSS 13 (see section IV-A-2) was traced (after several false leads) to hairline cracks in the electroplated corner areas of the waveguide diplexer hybrid coupler sections. This diplexer, which originated from DSN spares, was returned to JPL for R&D repair and replaced with another unit of the same type (a preproduction prototype) which had all suspect corner areas soft-soldered. By March the overall system again degraded to an IMP level of -160 dBmW and occasionally worse. Again it was traced to the diplexer. The prototype was replaced early in May with the original unit, which had been removed in January. Identical soft-soldered repairs had been made on the original unit. Since this change, the overall system performance with the flat plate reflector has remained below -180 dBmW.

The prototype diplexer removed in May was found to have additional hairline cracks on the interior broadwall surfaces of both hybrid sections. It is believed that these cracks were the source of IMP. The manufacturer has since informed us that the prototype unit was unique in having plated-over fabrication seams at the locations of the observed hairline cracks. No other DSN high-power diplexers have these peculiar seams.

Although the DSS 13 diplexers continued to operate without measurable IMP (≤ 180 dBmW) since soft solder repairs, it is felt that the mechanical design of these units is not reliable and their long-term performance is unpredictable. Further temporary repairs may not be possible; a high risk is involved in continued reliance on these units.

At DSS 14, two such soft-soldered diplexers continued to operate satisfactorily (< -175 dBmW during flat plate tests) from February to mid-September (1973), the end of the test program there. Again a high risk is involved in operating these temporarily repaired equipments; the mechanical design must be changed. It is recommended that the entire 64-m network be refitted with improved reliable units as soon as possible.

4. Transmit Filters (MTF)

The above experience with hairline cracks in diplexers prompted the soft-soldering of all tuning screws in the MTF. One test of the DSS 13 system with an unsoldered MTF yielded a reliable -170 dBmW IMP, while the same system measured < -185 dBmW with the soldered filter. The soldering process does not measurably affect the electrical characteristics of the MTF, and all MTFs now in R&D dual-carrier use at Goldstone DSCC are soft-soldered. As presently constructed, these units clearly violate guidelines of inspectability, and fluid and corrosion traps are present. Despite these shortcomings, the performance was found generally acceptable, probably due to the silver-soldered type construction. New units of this type, because of the impossibility of visual inspection, must remain suspect until RF tested.

5. Waveguide Switches

In January, 1973 at DSS 13, a strong erratic IMP of typically -130 dBmW appeared which correlated with light tapping on the waveguide switch rotor hub. The switch was removed, disassembled, and found to have mating scratches on both rotor and stator cylindrical surfaces. These scratches could have been caused by a small metal chip or other debris caught in the 0.15-mm gap between the two parts, although no such chip was actually found. Subsequent testing of the dual-carrier system, with the switch removed, failed to produce any further high-level IMP. The erratic and vibration-sensitive nature of the original IMP and the visual evidence of an internal fragment have led us to believe that a small particle lodged between rotor and stator was indeed responsible for the problem. This particular switch was simply reassembled and reinstalled in the DSS 13 dual-carrier system at that time and has operated without adverse effect.

At DSS 14, two waveguide switches (one in the PDS feedcone, the other in the SMT feedcone) caused noise bursts and IMP for still another reason. Because of these switches, both systems showed erratic performance in the flat plate mode, as great as 100 K noise bursts and -150 dBmW IMP. On disassembly, both switches were found to have corrosion and deep machining marks on mating surfaces of the two rotor parts. These parts were cleaned, lapped, greased (exactly as in waveguide flange preparation), and reassembled. Since the switches were reinstalled, both feeds have consistently shown <-175 dBmW IMP and no noise bursts in the flat plate mode.

It is probable that the DSS 13 and other DSN switches, operating without lapped and greased rotor parts, pose additional risks which should be corrected as schedule permits.

6. Rotary Joints

The quiet system performance that was uninterrupted since early May 1973 at DSS 13 (<-180 dBmW IMP and no detectable noise bursts) did not degrade on the occasions when the two rotary joints added to the feed system in January were actuated. Time has not allowed us to compare the conductive grease used

within the ball bearings of these units against nonconductive grease. As is the case with waveguide switch ball bearings, continued use of conductive grease is recommended.

At DSS 14 one rotary joint in the PDS feedcone caused massive noise bursts (and occasional but not consistent transmitter high back power tripoffs) for a reason not observed at DSS 13. This component is shown assembled in Figure 37 and disassembled in Figure 38. A closeup (Figure 39) shows unmistakable arc pitting and metal galling. This damage was so extensive as to preclude a determination of whether a metal chip initiated the arcing, which then presumably contributed to the galling in the 0.25 mm choke gap. This event again demonstrates the extreme cleanliness needed in assembly of the waveguide system. Both remaining rotary joints in the PDS feedcone have operated without incident for approximately 5 years of heavy DSN and developmental radar service. Two units, returned from DSS 43, failed for a completely different reason. The initial assembly did not include proper bearing preload; thus the two sections of the rotary joint were free to wobble slightly and nearly contacted one another in the wrong regions. Light evidence of arc pitting was found.

7. Orthomode Transducer

Although the PDS or SPD system main orthomode sections are fairly massive units without internal seams (save one central flange), the rectangular waveguide impedance matching sections contain inductive and capacitive iris sections. These sections have caused large noise bursts with power as low as 1 kW single carrier when fractured, again demonstrating the extreme need to visually inspect for cracks and to provide stress-relieving bracketry.

8. S-Band Traveling Wave Maser

During DSS 13 dual-carrier operations in February, 1973 it was discovered that moderately strong IMP (-155 dBmW) and occasional noise bursts appeared in the receiving system whether the maser input was switched to the maser calibration ambient load or the diplexer TWM port. Upon investigation, it was found that one of three flange bolts was loose on the 22-mm (7/8-in.) coax to waveguide transition on the maser input. When these three bolts were

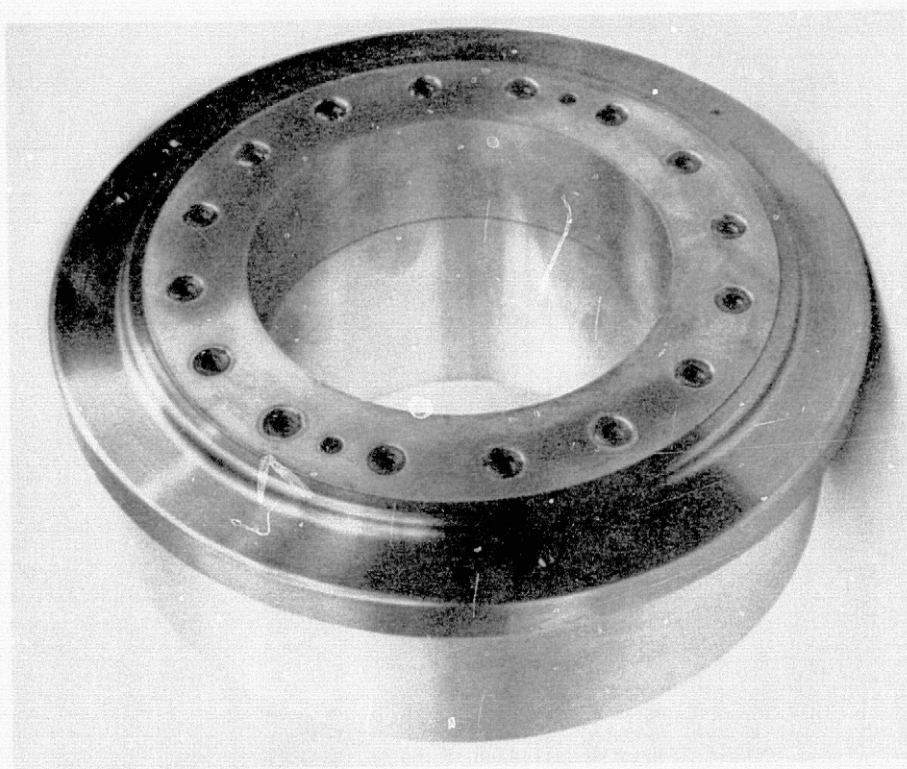


Figure 37. Assembled S band rotary joint

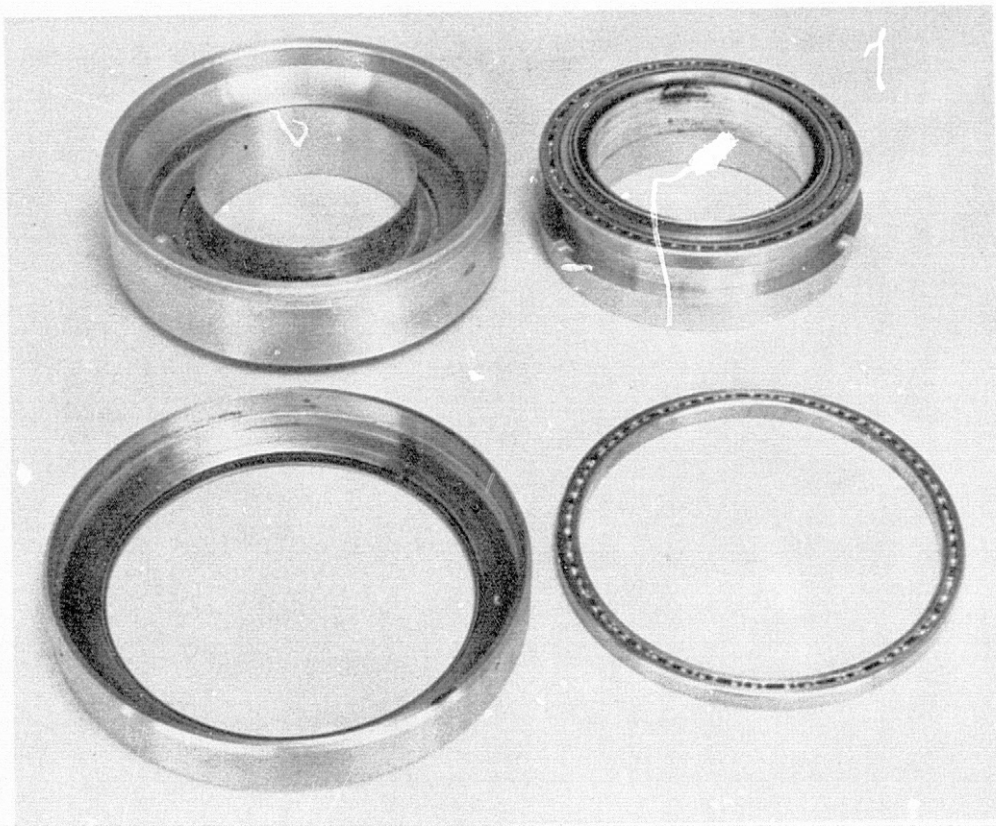


Figure 38. Disassembled S-band rotary joint

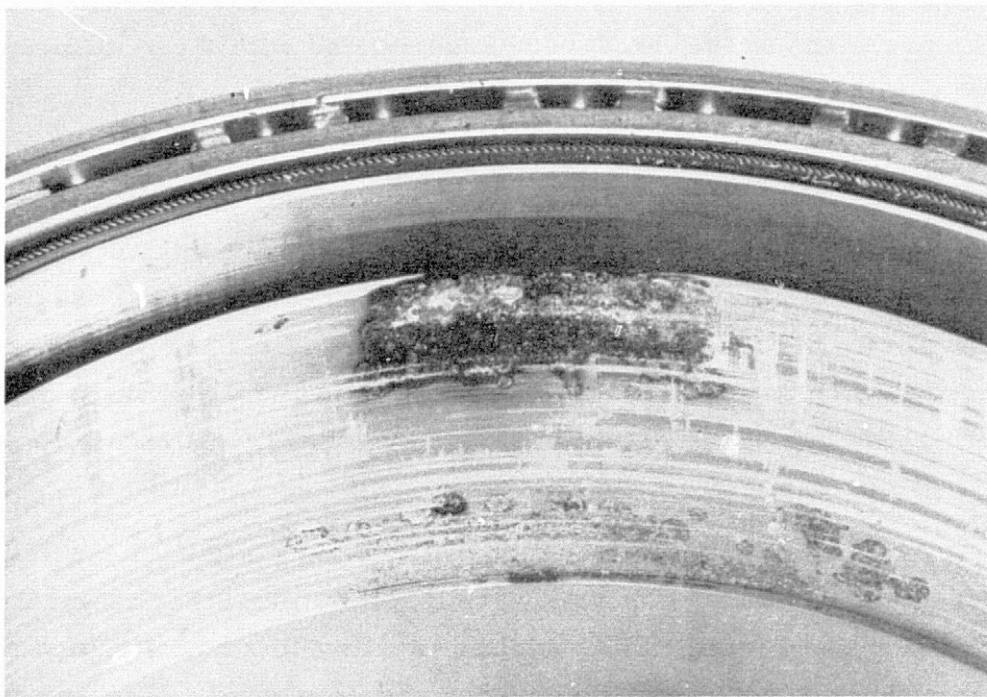


Figure 39. Closeup of rotary joint pitting and galling

being adjusted, the IMP could be made to vary from -135 dBmW (all bolts loose) to an undetectable level. It is believed that the loose bolt condition resulted in IMP generation at the poorly contacting coax outer conductor from (1) transmitter carrier leakage into the loose coax interface from the ambient environment and/or (2) normal transmitter carrier conduction via the diplexer TWM port (roughly -20 dBmW).

This IMP/noise burst problem with the TWM was eliminated by tightening coaxial flange bolts on the maser input waveguide transition and relieving excessive mechanical stress on the transition by inserting a flexible seamless bellows-type waveguide section between maser and maser waveguide switch. No similar problems of this kind were experienced with three different S-band maser installations at DSS 14.

9. Flat Plate Reflector

This device is a 1- by 2-meter aluminum plate mounted directly over the feedhorn at an angle of about 30 deg from vertical. Supporting brackets for the plate attach to the feedhorn and feedcone roof. Because of frequent disassembly needs, each metal part of this assembly is insulated from other mating parts through the use of dielectric bushings, washers, and shims to insure noise-free performance.

During a few instances of assembly of the flat plate over the feedhorn, inadvertent metal-to-metal contacts were made by incorrect assembly of the dielectric and metal parts. This resulted in many lost hours of test time before this source of noise was discovered and corrected. Design and installation of a flat plate test structure must be carefully planned so that the difficult erection on the antenna can be performed quickly and correctly.

10. Long-Term Waveguide Test

The long run of copper waveguide at DSS 13, consisting of many straight and elbow sections, measures approximately 15 meters in length. The assembly was cleaned, lapped and greased, and reassembled in October 1972, strict attention being paid to DSN waveguide assembly procedures. Since installation, (1) components at each end of the run have been removed and reinstalled many

times,²⁸ and (2) the assembly has been operated with dual 10-kW carriers for a minimum of 2000 hours and with a single 70-kW carrier (for burn-in) for perhaps 150 hours. Therefore, it is significant that this assembly still remained quiet after 10 months of dual-carrier operation on the frequently moving (flexing) antenna structure at DSS 13.

Waveguides at DSS 14, after more than 2 years' service, have been disassembled and inspected particularly for flange corrosion or other problems. The recommended waveguide assembly procedures are found entirely adequate.

11. Long-Term System Test

Early in 1973, completely acceptable noise performance in the flat plate mode was achieved in both PDS and SMT feedcones at DSS 14 (NB less than 1 K, IMP below receiver threshold, -175 dBmW). The flat plate was then removed and stowed while the noise abatement program gave full attention to the external antenna surfaces. During this final phase, the flat plate was erected on several occasions to verify that the noise performance of the internal system had not deteriorated, i.e., to ascertain that all observed noise was from exterior surfaces. This was indeed the case throughout the balance of the program and is considered a significant finding. Following repair of the internal waveguide problems, the complete internal system performance was entirely stable during the final six months of the program. Flat plate reflectors should be a part of the test equipment at all DSN stations. The DSS 14 program ultimately answered the question of flat plate isolation in the quadripod environment. It is adequate over somewhat more than 250 dB, at least on a reasonably "clean" antenna. We conclude with certainty that the upgraded methods used in the DSN internal system are fully capable of providing reliable noise-free performance at either 400-kW single, or dual 40-kW carriers, for $N \geq 31$.

²⁸In particular, the number of end-for-end swaps of the two diplexer assemblies used, in attempts to locate very low level IMP, probably exceeds a dozen.

E. EXTERIOR ANTENNA SURFACES

The approximate order of preference for noise abatement on outdoor antenna surfaces is given in this section. A great difficulty is recognized in dealing with noise sources on the outdoor parts. Throughout the DSS 13 and DSS 14 programs, consideration was given to identifying signatures or amplitudes from various locations or types of noise from various objects. The unfortunate aspects of maintaining a time-constrained program did not allow anything resembling an orderly approach. Two obvious aspects associated with outdoor noise problems must be considered in determining the need for modification:

- (1) The power density zone in question
- (2) The visual quality of the specific connection.

Modification methods, in order of preference (by experience), are listed below:

- (1) Removal. Many small items and a few large items of non-essential hardware were disposed of entirely or removed to a position of low RF power density.
- (2) Replacement. Other items of hardware were replaced with noise-free units where it was impractical to effect field repairs. Economic considerations often prevented applying this method when desired.
- (3) Bonding (Welding, Brazing, and Soldering). From a noise abatement standpoint, bonding is the most reliable method of fastening two conductors together. Welding of questionably bolted or riveted joints and overlapping seams was the method of outdoor noise abatement used most at DSS 14.

When a risky interface between two conducting surfaces cannot be removed or replaced and cannot be bonded because of (1) dissimilar metals, (2) the need for occasional disassembly, (3) inaccessibility, (4) sensitivity to

heat accompanying the welding process, etc., then the following less attractive methods must be used:

- (4) Machining/Lapping/Greasing. Where practical, mating surfaces can be machined flat, lapped, lightly greased, and bolted exactly as in waveguide flange preparation and assembly. Of concern is the potentially harmful effect of outdoor weather on this type of joint.
- (5) RF Shielding/Choking. Shielding of the contact area can reduce the incident RF power density upon it and thus reduce noise generation. Aluminum tape with an adhesive backing has been used extensively to permanently shield flat seams between main reflector panels, as well as temporarily shield hatch covers, door handles, etc.

This method is sometimes undesirable because of the difficulty of designing an effective shield and estimating its performance. Although aluminum tape was applied to many such items as door seams, door latches, hatch covers, nonweldable seams, etc., it should be remembered that this was strictly a temporary, inconvenient, and high nuisance maintenance measure which was required because more suitable permanent measures could not be implemented during the program. Significant followup attention to these temporary means is needed. In a few locations, RF choking (particularly of the waveguide-beyond-cutoff variety) may be advantageously (simply) applied.

- (6) Insulation. Electrical insulation can be inserted between otherwise contacting parts. Dielectric sheets, shims, bushings, and washers have all been used for this purpose at DSS 14. In a new development, load-carrying insulated joints of epoxy were used to mount S/X dual band feed hardware for the follow-on units.

In general, use of insulators in dirty environments is not recommended unless dedication to requisite maintenance is understood. Further, weather effects (rain, fog) may provide short circuits across these elements which could lead to intermittent contacts. Indeed, evidence was discussed which shows that a thoroughly wetted antenna is substantially quieter than when partially dried out, at least for the case prior to substantial outdoor abatement. In most of our applications of insulation we attempted to minimize the numbers of locations but, when needed, to generously provide for long paths across the insulator.

- (7) Absorption. Microwave absorber material is not recommended for use as a cover for suspected noise sources. It was not satisfactorily proven to be a noise-free material; it is a fire hazard; it deteriorates rapidly in an outdoor environment; and, if used extensively, will have an adverse effect on receiving system noise level, by thermal radiation.

VI. FUTURE DESIGNS, OPERATIONS, AND STUDIES

A. PHILOSOPHY OF DESIGN AND MAINTENANCE

Designers must be made aware of present hardware deficiencies and the relatively simple available means for correcting most of them. It is recognized that conflicts will occur. Outdoor personnel access, convenience items, and safety-related hardware on the antennas were found to be the worst offenders and frequently the most difficult to correct. Simple convenience items must be drastically if not totally dispensed with. Another "trapdoor in the dish" or handy telephone box may represent hundreds of unacceptable joints in the DSN noise abatement context and is most easily and economically handled by total elimination, wherever possible, preferably in the design phase but not unreasonably later (full panel replacement to eliminate trapdoors, for example).

Field personnel in construction, maintenance, and operations areas must likewise adhere to approved practices during initial implementations and follow-on maintenance and operations. We emphasize the few or single bad joint

demonstrations and the resulting interference occurring repeatedly on this program. Without proper design, one cannot achieve good performance; without proper maintenance, performance cannot be relied upon. Reliable daily performance reporting and monitoring by a central and responsive organization is considered a necessary element in the successful operation of the widespread network of DSN antennas. It is suggested that a single individual should constantly review status and performance for all net stations. This individual should be authorized to direct special tests and RF burn-in procedures, including dual-carrier stress tests, as indicators of possible impending major problems, as discussed.

B. FUTURE DUAL-CARRIER OPERATIONS

Given appropriately designed, installed, and maintained equipment, there is no fundamental reason why the DSN cannot support multicarrier missions. We suggest some caution, however, since (1) as noted, not all required rework has been accomplished, even at DSS 14, (2) weather, particularly rain and/or fog remains a poorly understood effect, and (3) required maintenance might represent a high cost item. Selection of uplink frequencies spaced to allow only high orders of intermodulation ($N > 40$, $IO > 81$) and/or reduction in transmitter power are obvious further means of alleviating the problems in a marginal situation or increasing reliability in an otherwise acceptable situation.

C. RECOMMENDATIONS FOR FUTURE

1. Frequency management cannot be overstressed. Should use of the entire allocated 8.40-8.50 GHz downlink band become a DSN requirement, the 4th harmonic of the S-band uplink (and associated IMP centered on that harmonic) will require elimination or substantial control. Hopefully, problems of this nature will receive closer scrutiny in the future, even recognizing the international nature of such frequency allocations. Internal frequency management, in selection of exact frequencies used for 2.1 GHz uplinks, goes a long way in minimizing IMP in at least the 2.3-GHz downlink band. As mentioned, possible future higher frequency dual-carrier uplinks (X-band) may encounter even more severe problems than those discussed due to smaller N-indices (lower orders of intermodulation).

2. The analytic connection between amplitude of low-order (e.g., 3rd) and high-order (e.g., 63rd) intermodulation products requires study. Specifically, the question frequently arose: is our difficulty in controlling IMP in the high orders in part due to the significant low orders (a result of DSN systems design) being simultaneously transmitted ("rainbow" illumination of internal and exterior parts)?

3. Although the programs described were effective in achieving significantly lower levels of interference, much work, particularly in the outdoor areas, was crudely and hastily implemented. Studies of simple fieldworthy but moderately effective electromagnetic shields should be undertaken. Elimination of metal tape (a high maintenance item) would be desirable. Further study of micro-cracks (length, width, depth and polarization orientation) with respect to wavelength, skin depth, and current density should be undertaken to more fully understand acceptable versus unacceptable deficiencies. At the present time this judgement is based only on limited field experience. The magnitude of contact pressures for bolted connections, in the skin current environment, requires further understanding. The bibliography includes evidence that ferromagnetic materials are responsible for nonlinear mixing, given sufficient current density. Since steel is used in DSN antenna quadripod structures, estimates of possible future power level difficulties should be made.

4. As noted in several areas within this report, many needed modifications in the outdoor areas were not accomplished during the programs. Specifically, many items were simply shielded on a temporary basis. If followthrough to these initial results is desired, significant attention to these details will be required. Again, the authors stress outright elimination as a preferred technique to many of these problems.

5. Maintenance personnel should not assume that presently established familiar practices are adequate in the new environment of higher power multiple uplinks. Many unfortunate maintenance practices have understandably become routine since, on a typical noisy installation, a small addition to or deletion from a large amount of noise making hardware goes unnoticed. A few, or even one offending items will become very visible once the large effort of removing or modifying most of the noisy hardware is made.

6. An increased awareness of present technical demands on the DSN microwave and antenna subsystems must be shared by the operating organizations. The fact that yesterday's noise bursts did not result in a data loss and discrepancy report should not be interpreted that no problems exist.

ACKNOWLEDGMENT

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APPENDIX A

TWO EXAMPLES OF DESIGN: THE DSN S/X REFLEX DICHROIC FEED

In this section, the prototype reflex-dichroic feed system is first described (in the sense of its shortcomings) and then the follow-on units. It is hoped that these examples will aid in establishing the preferred philosophy of design and maintenance of outdoor DSN equipment.

During the noise abatement program, it was realized that the prototype dichroic feed system would be a significant offender as far as noise interference was concerned. This system was considered especially risky since the power densities on each reflector are the highest to be found on the outdoor surfaces of 64-m antennas (essentially duplicating feedhorn aperture power densities). Although the prototype unit remained on the antenna during most of the DSS 14 program, it was possible to effect an extensive redesign of follow-on units based on our noise abatement experience as of that time. In retrospect, the prototype hardware was exceptionally poorly designed from a noise interference standpoint.

Figures A-1 and A-2 show the prototype ellipsoidal reflector backup framework during shop construction. The fabrication technique, which employed discrete aluminum tubes, plates, angles, and clips, was convenient (and possibly appropriate) for a limited operational prototype unit. All connections are either bolted or riveted or both. A closeup of one of the connections (Figure A-3) reveals the myriad of joints capable of producing IMP, if not low-level arcing, by simple visual inspection.

Figures A-4 and A-5 show the prototype ellipsoidal reflector and dichroic plate as initially installed on the DSS 14 tricone assembly.²⁹ Simply for ease of manufacture, the dichroic plate was divided into two regions: the active 1-m-diameter part containing resonant apertures (Figure A-6) and the 2-m-diameter carrier. The joint between the two was prepared much like a waveguide flange (flat clean surfaces, grease protection) with at least 5 bolts per

²⁹ An additional view is available in Section IV (Figure 29). In Figure 29, the frequency of bolting of the feedhorn to feedcone roof interface should be especially noted.

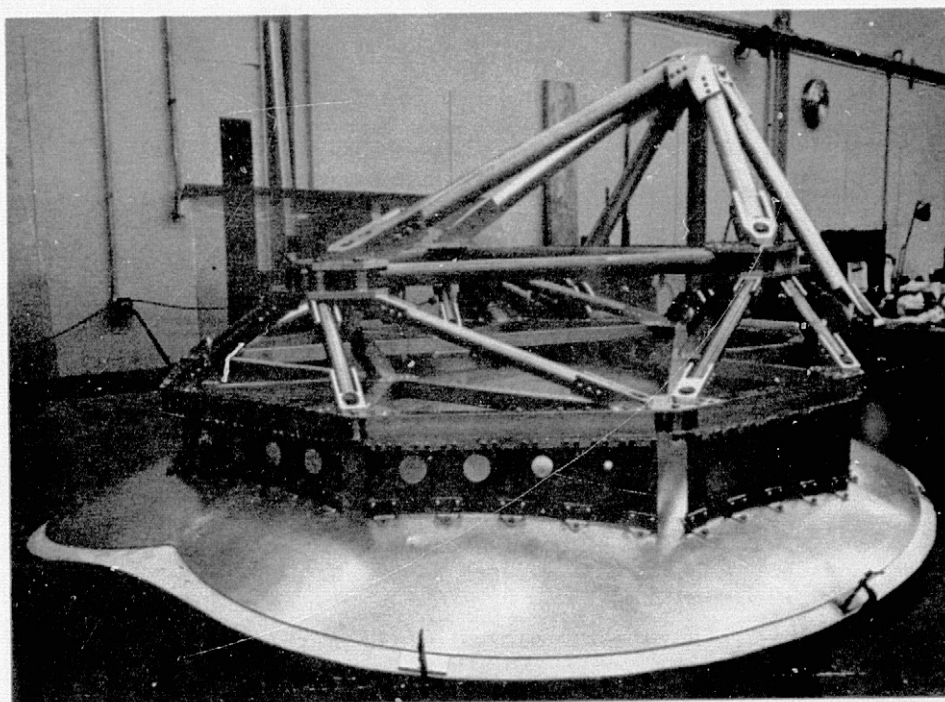


Figure A-1. Prototype ellipsoidal reflector assembly, side view

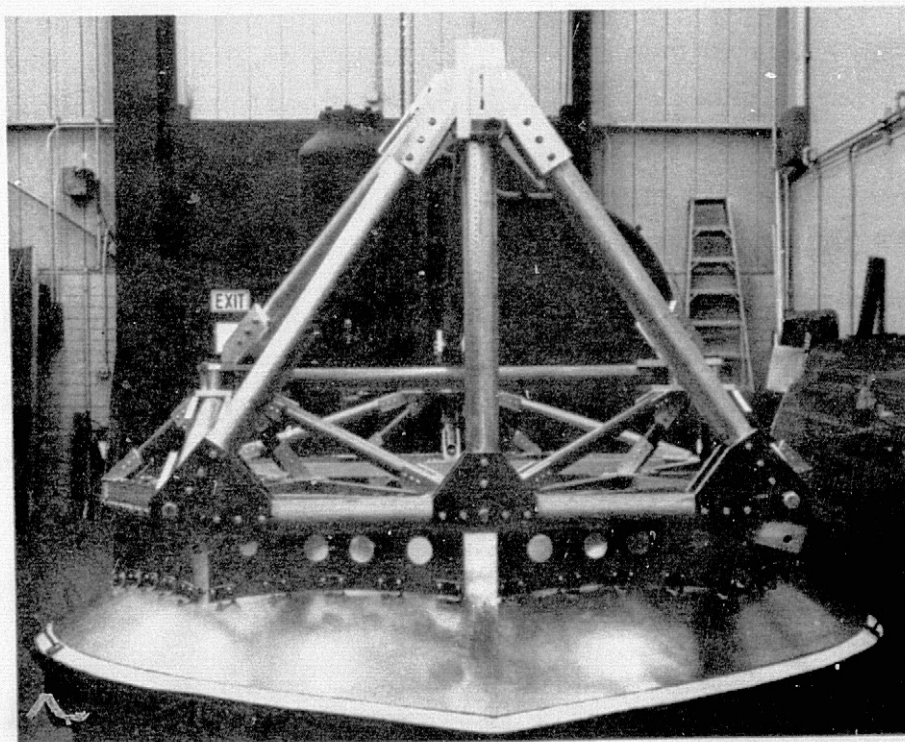


Figure A-2. Prototype ellipsoidal reflector assembly, end view

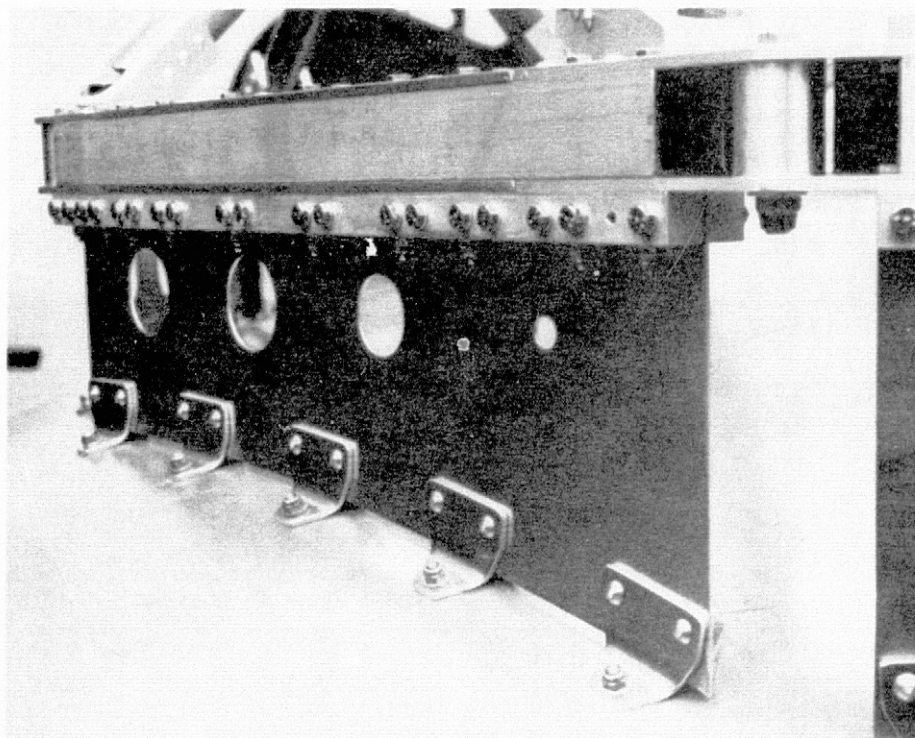


Figure A-3. Closeup, ellipsoidal reflector connections

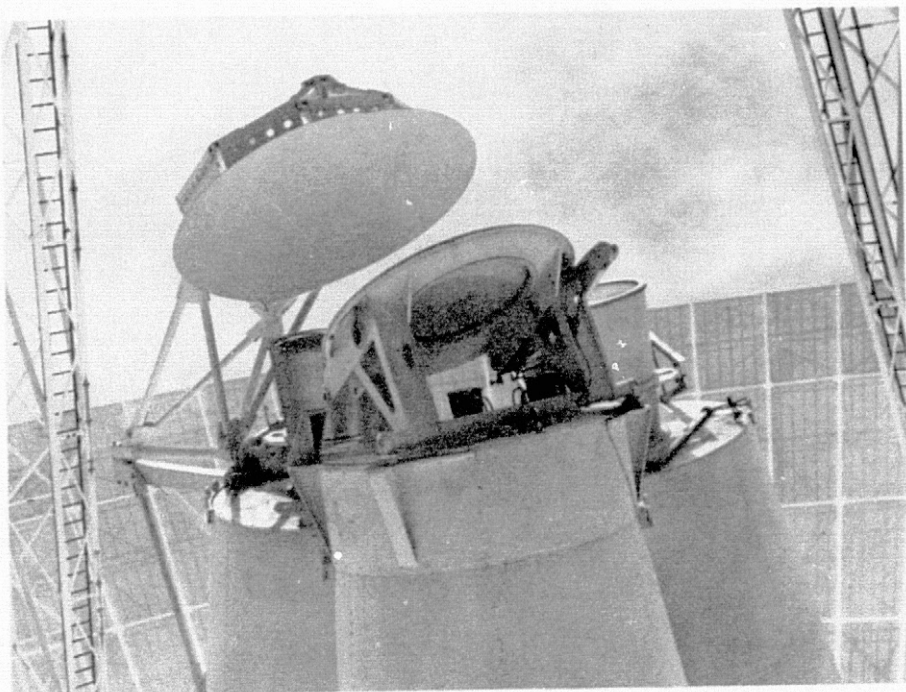


Figure A-4. Prototype S/X feed at DSS 14, extended

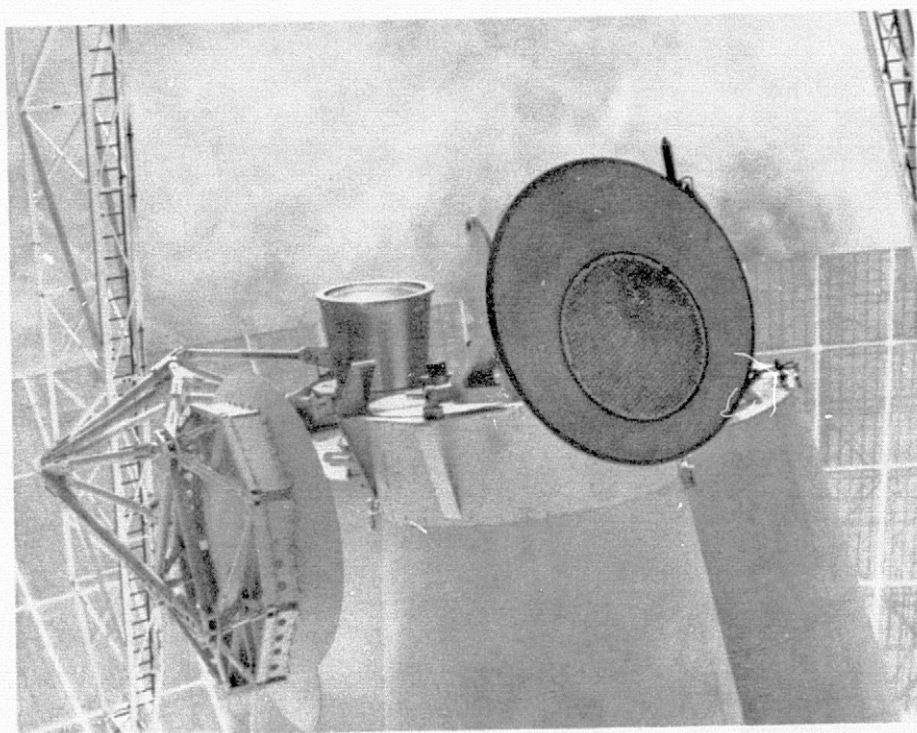


Figure A-5. Prototype S/X feed at DSS 14, retracted

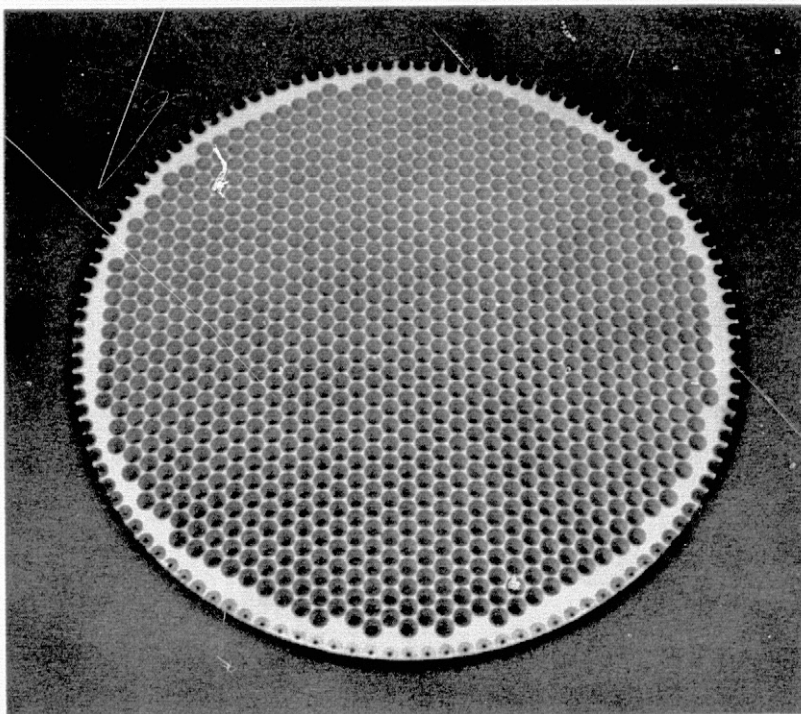


Figure A-6. Prototype dichroic plate, active region

S-band wavelength. Although this particular joint operated without incident for many months of outdoor exposure, it represented a needless risk. To compound the above problems, the necessary RF test feature of including retracting mechanisms for both reflectors is present. These mechanisms include bushings, bearings, hydraulic hoses, fittings, petcocks for bleeding hydraulic fluid, limit switches, outdoor connectors and wiring — all exposed to some degree to subreflector illumination. The only additional measure taken with this equipment (just prior to prototype installation) was to tack weld normally bolted items such as support arms (ellipsoid frame to feedcone) and trunnion pads (dichroic assembly to feedcone). The number of inaccessible details impossible to correct overshadowed what was done by far. As described in Section IV, this hardware severely limited IMP performance at DSS 14.

The redesigned follow-on hardware is seen in Figure A-7. Simple elimination of the retracting mechanisms resulted in a most difficult task becoming practical. The backup framework assembly has been redesigned using only tubes and plates, 100 percent welded. The critical joints connecting the purposefully flexible frame plates to the precision ellipsoidal reflector are of cast epoxy resin, selected for high insulation resistance and low water absorption. The interface joints at the feedcone connection planes are insulated, using fiberglass sheets, blocks, bushings, and washers, to accommodate the need for occasional disassembly. One of the detailed connections is shown in Fig. A-8. Figure A-9 shows another interface joint utilizing completely insulated hardware (sheets, bushings, and washers). The guidepins (for precision reassembly) seen in Figures A-8 and A-9 are of dielectric material. Despite the rugged outdoor nature of this equipment, it is possible to design easily installed and maintainable connections which allow occasional disassembly and which are completely insulated.³⁰

In Figure A-7, the dichroic plate is seen to be of single construction, despite slightly increased costs. Unfortunately, Figure A-7 illustrates some nonconformance with good practice. Although both feedcones shown are 100 percent

³⁰These connections are also insulated on the inside of the feedcones even though not required from an RF standpoint. This was deemed necessary to allow simple dc resistance tests to be performed (1) immediately following installation and (2) as a preventative maintenance test point.

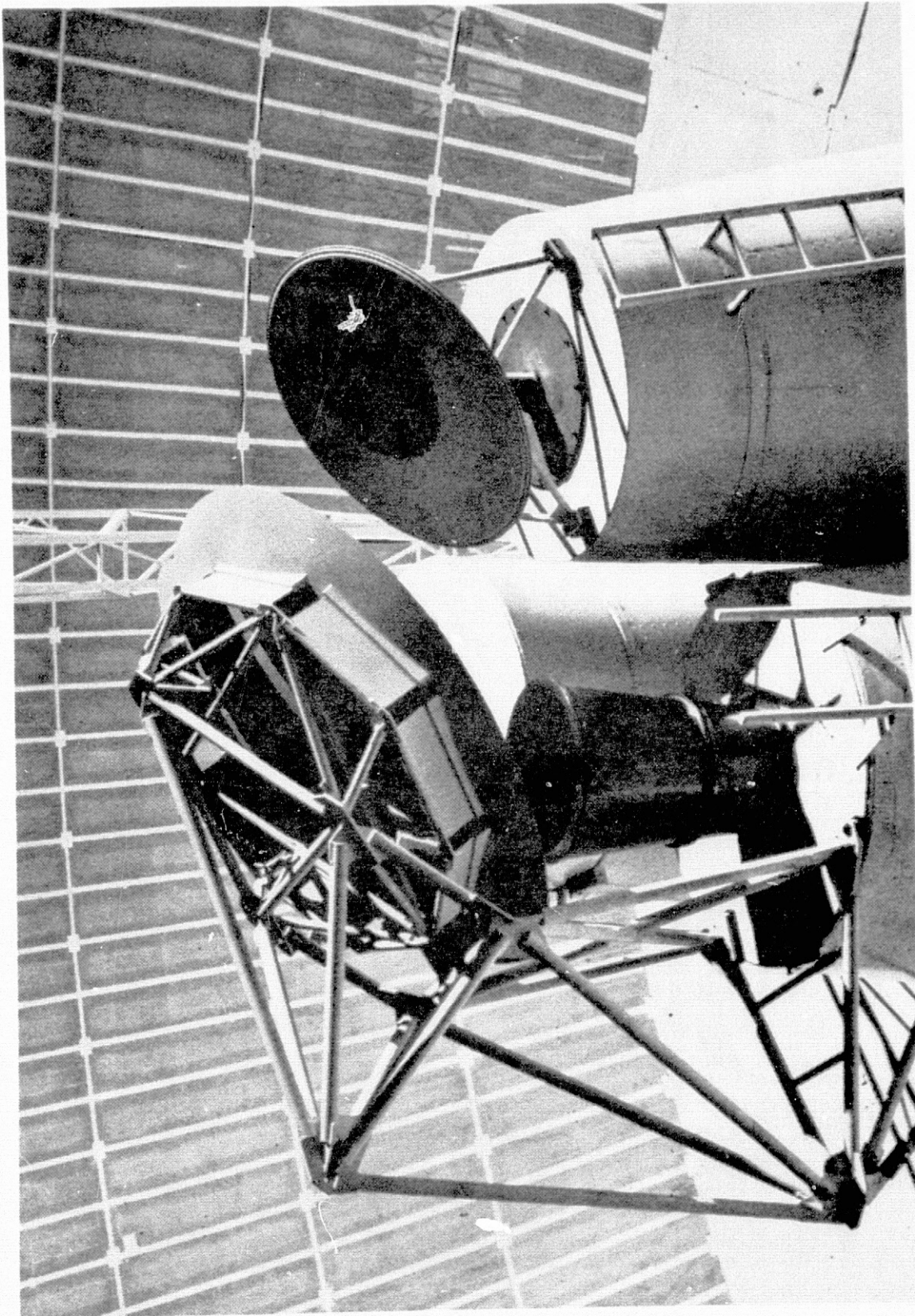


Figure A-7. Redesigned follow-on S/X feed at DSS 14

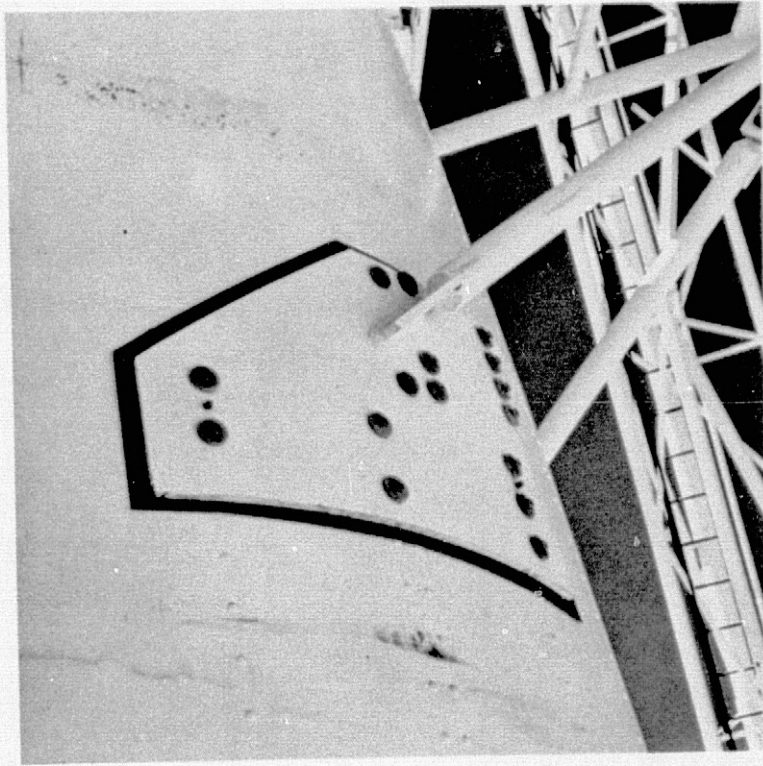


Figure A-8. Insulated connection, follow-on S/X feed

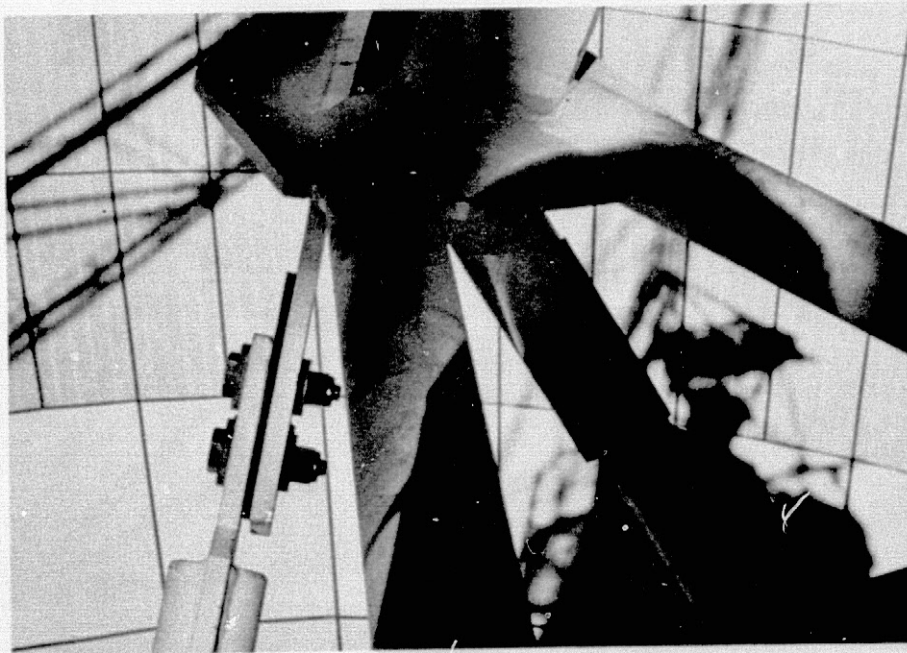


Figure A-9. Interface joint, follow-on S/X feed

welded on the outside, the S-band horn mounting flange is not yet sufficiently bolted on a "5 bolts minimum per RF wavelength" basis. This feedcone system was constructed prior to full understanding of the necessity to thoroughly RF-bond this area and will require difficult and costly disassembly/rework. The X-band feedcone horn mounting flange in Figure A-7 is apparently also not sufficiently bolted; actually it rests on an 0.1-mm-thick insulator.

The only known deficiency of the follow-on design is the insulators. If directly assembled (as was done on the first follow-on installation at DSS 63), the insulator joints seem to have the same affinity for water vapor as do ungreased waveguide flanges, by capillary action. After 3 months of successful operations, the first heavy rain resulted in increased noise, thought to be caused, in part, by the semishorted (at dc) insulators. Improved installation technique (including filling all possible capillaries and voids with silicone grease) should prevent a recurrence of this problem. Some maintenance attention to the paint protection on the load-bearing epoxy joints is advised. Paint erosion and subsequent weather deterioration of the epoxy could be disastrous (especially if wet) in the RF environment. Use of insulators in the best of conditions should be recognized as a future maintenance item, requiring occasional inspection, cleaning and/or replacement. The built-in test points should be useful in this regard.

One obvious lesson in the above is that early design decisions (for example, what might be appropriate for a prototype design) are often difficult, if not impossible, to correct later. Prototypes have an uncomfortable tendency to be long-lived in the DSN. Also, vintage prototype hardware is frequently resurrected (to meet some transient need) despite the designers' express wish that it not be reused.

APPENDIX B

DSN 64-METER ANTENNA NOISE ABATEMENT AND TAPE APPLICATION FOR EXTERIOR SURFACES

I. INTRODUCTION

Practical large-aperture reflector antenna systems are presently constructed with dissimilar metals and hundreds of modular components (reflector panels, feed support trusses, feedcones, and others). The sub-assemblies, when combined, may be undesirable from a microwave noise point of view when the system is simultaneously transmitting very high power and receiving very low level signals at slightly different wavelengths. The ideal (but impractical) construction method would be to form a solid weldment of unambiguous high-reliability bonded joints; this would further result in little or no follow-on maintenance in the microwave noise context.

The purpose of this appendix is to describe methods of joining many of the separate antenna outdoor components into a quasi-homogeneous assembly by use of a relatively crude but practical aluminum tape RF bypass capacitor system. This system may alternately be viewed as consisting of low-performance (15-30 dB) electromagnetic shielding. Secondary purposes of this appendix are to (1) illustrate where intentional insulators may be applied to advantage, (2) to place more substantial and permanent noise reduction methods, such as welding, into proper perspective, and (3) to touch upon necessary ongoing maintenance requirements for the external antenna.

The ingredients of most noise-producing mechanisms are a microwave field environment in which two or more conductors are in close proximity, i. e., actually touching, overlapping, rubbing, or separated with either a very thin layer of oxide or a thicker but unreliable layer of paint, scale, or debris. Mechanical flexure, unavoidably present in large structures, coupled with typical large numbers of component parts, leads to a high frequency of occurrence of intermittent contacts on an uncontrolled installation. Whether the physics of the noise phenomena is an arc, a nonlinearity without plasma, or more sophisticated possibilities (or more than one of the above) is not clear, but that is immaterial for purposes of this appendix. Suitable procedures have substantially reduced and controlled the situation.

This appendix first outlines and comments on major antenna areas of interest and then fully details taping procedures developed to reduce microwave noise from simultaneous transmission/reception on common reflector antenna surfaces. The procedures are a result of real-world considerations of handling relatively rough outdoor hardware on a very abbreviated time scale program. By describing the procedures in detail, it is expected that others can at least duplicate the favorable results previously obtained; moreover, it is hoped that others will thereby be encouraged to innovate and develop improvements based on further field experience.

II. MAJOR AREAS OF INTEREST

The exterior surfaces of the DSN 64-m antennas can be grouped into five general locations, in order of increasing importance for noise abatement: main reflector, tricone structure, antenna feedcones, quadripod legs and apex, and subreflector. This section will discuss, in general terms, the characteristics and requirements of each location.

A. MAIN REFLECTOR

The 64-m-diameter main reflector surface consists of 552 separate aluminum skin panels with numerous access doors and openings, and includes the complex interface at the base connections of the quadripod legs to the main reflector backup framework. There are approximately 3400 m of primary panel gaps (between individual panels) and 1400 meters of butt joints (within individual panels) which require attention in order to provide a noise-free surface. The main reflector experiences a lower incident power density than any of the following locations but is potentially a significant noise generator because of the large numbers of undesirable details.

B. TRICONE STRUCTURE

The tricone structure consists of a bolted and riveted assembly approximately 8 m high and 6 m in diameter. Its function is to support the removable antenna feedcones at the proper height above the main reflector vertex and to house heavy transmitting and receiving equipments. The tricone contains

numerous doors, hatches, seams, and details which are neither reliably bonded nor insulated. Because it is closer to the illuminator, with consequent higher incident power density, it requires more careful attention than the main reflector. At DSS 14, as configured for 400-kW single- or 40-kW dual-carrier service, the tricone seams were welded wherever possible. One major aluminum-to-steel joint near the bottom was treated with aluminum tape, according to procedures given later in this appendix. Removable covers, to accommodate occasional disassembly for main reflector optical surveys, were insulated. The two remaining 64-m stations, as configured for 100-kW single- or 10-kW dual-carrier service, will be taped in the tricone seam areas. This structure is one of the most difficult items to tape because of physical access and shape problems.

C. ANTENNA FEEDCONES

The antenna feedcones are each approximately 5 m high and 3 m in diameter. They function to house the Cassegrain feedhorns, microwave polarizing equipments, low noise preamplifiers, and final transmit/receive (duplexing) filters, at the proper height above the tricone. As originally constructed, the antenna feedcones consisted of bolted and riveted sub-assemblies, with neither reliably bonded nor insulated seams. Two major access doors and many details such as ladders, grabrails, and crane lifting lugs were demonstrated troublesome noise sources. Because of the difficult shapes involved (convex and concave joints over short distances) and closer proximity to the illuminator with consequent higher incident power density, total or substantial welding in this location is considered the only noise improvement alternative.³¹ In a few selected areas (feedcone doors), insulation was successfully applied. Also, points of frequent disassembly (feedcone base to tricone interface) are handled by insulation. In one critical area (feedcone roof to feedhorn mounting ring), both waveguide-flange quality bolted connections, and insulated interfaces were successfully applied in order to maintain the option of future feedhorn disassembly. Aluminum tape use in this location is not recommended, with the possible exception of for covering minor details on locally plane surfaces only.

³¹ Because various generations of all-welded feedcones have been constructed, thorough inspections of all units presently in 64-m network service is advised to verify full compliance.

D. QUADRIPOD AND APEX

The quadripod and apex is a structure approximately 30 m high, consisting of nominally 100% shop-welded steel tubing, arranged in truss-work form. Each quadripod leg is approximately 1 by 4 m in cross section. The primary function of the quadripod is to support the Cassegrain subreflector; one secondary purpose is to function as a crane boom which, together with the antenna elevation angle drives, provides the means to lift heavy equipments into place (complete feedcones, transmitters, etc.). Although the basic quadripod legs are completely shop-welded (except for a few splices near the upper end), many important details in a noise-abatement context are not. Access ladder attachment points, electrical conduits for lighting, cable blocks and pulleys, the plumbing to supply high-pressure air to the apex (primarily for the infrequently used subreflector hoist), and others, are typically very poorly bonded as originally installed. Such joints and seams cannot be taped; welding is considered the only alternative. The base connections of the quadripod legs to the main reflector backup framework are in a complex (standing wave) microwave field region, due to reflections. Power densities 6 dB and more can be expected here, compared with the illumination which would be present without the added complexity. Thin sheet metal plates are affixed, by welding, to the more massive members in these locations (to permit flexing), and a final small gap to the main reflector panels is treated with aluminum tape, according to procedures given later in this appendix.

The apex location contains a myriad of unbonded and uninsulated hardware, including the primary rotational drives for the subreflector (including sliprings), secondary x-, y-, and z-axis positioning drives, the subreflector installation crane boom, hoist and cabling as well as intercom and telephone services, to mention a few.

The approach taken to reduce noise from this location was primarily to relocate unbonded hardware deeper into the quasi-shadow-zone (defined to be a cylinder of 2 m less diameter than the subreflector) and secondly to bond, by welding, essentially everything outside of the defined cylinder (a few permanent shields were used). Typical joints in this location cannot be taped.

E. SUBREFLECTOR

The 7-m-diameter subreflector consists of a center hub and 12 major and 12 minor lightweight aluminum skin panels. The hub is perforated with access holes for purposes of optical alignment. There are approximately 100 m of panel gaps (between individual panels) which require attention in order to provide a noise-free surface. The subreflector experiences a very high incident power density and therefore requires the greatest care to prevent noise generation. Poor procedures and/or materials in this location could be dangerous because of possible microwave induced heating and resultant fire hazard.

Owing to the complexity of backside joints and gaps, a design change to include a backside diffraction shield has been implemented. This shield consists of an 0.6-m-wide noise-free annulus on the rear of the subreflector, thereby providing a reliable conductor over a four-wavelength (minimum) radial distance in this quasi-shadow zone.

At DSS 14, as configured for 400-kW single or 40-kW dual-carrier service, the subreflector and diffraction shield were 100% welded. The two remaining 64-m stations, as configured for 100-kW single- or 10-kW dual-carrier service, will be taped in the subreflector and diffraction shield areas according to procedures given later in this appendix. Procedures should be followed carefully in this location and continued attention should be given to inspections and maintenance against weather induced materials deterioration. This location is the most difficult to tape due to physical access problems.

III. GENERAL METHODS AND MATERIALS

When noise abatement of the antenna exterior surfaces is undertaken, simple elimination of nonvital questionable hardware is the highly preferred first step. Where this is not possible, the next most desirable widely applied means of correcting problems are, in order of preference, (1) replacement, (2) welding, (3) bypassing or shielding and (4) insulating, all on a permanent basis. After applying the above preferences wherever possible, the resulting antenna will still exhibit many discontinuities such as cracks, gaps, and rough joints which cannot be directly and permanently prevented from

continuing as unwanted noise sources. The recommended method to avoid noise generation from these locations is to bypass or shield them from the incident microwave energy with the use of aluminum (and in some cases insulating) tape.

Tape should be recognized as a semipermanent labor-intensive solution, both initially during application and later during followon maintenance. For that reason, it should be applied only where permanent or preferred solutions are clearly impractical. Furthermore, use of tape includes some risk. If improperly applied (for example, if heavily wrinkled), it will by itself become a noise generator. Adhesion is a problem that is best handled by care and attention to detailed cleanliness during initial installation rather than in later maintenance sessions. Tape is fragile and sensitive to foot traffic; heavy loads impressed during equipment installations will typically damage it beyond usefulness.

Approved taping materials, for main reflector, tricone and subreflector locations are as follows:

- (1) Aluminum tape: 3M Co. Type 363, 100-mm (4-in.) width by 55-m (60-yard standard roll), fiberglass reinforced.
- (2) Aluminum tape square: 250-mm (10-in.) square by 0.08-0.12 mm (0.003-0.005 in.) thick, with acrylic adhesive and quick-release backing.
- (3) Kapton film: Kapton material, 125 mm (5 in.) width by 0.05 mm (0.002 in.) thick, 30-m (100 ft standard roll), with acrylic adhesive.
- (4) Kapton film square: Kapton material 300 mm (12 in.) square by 0.05 mm (0.002 in.) thick, with acrylic adhesive and quick-release backing.
- (5) Tape primer: 3M Co. Type 82 (for adhesion base).
- (6) Final paint: Triangle No. 6 Hi-Reflectance white paint.
- (7) Silicone rubber material: RTV-108, General Electric Co., caulking cartridges (used in subreflector location only).

Substitution of nonapproved taping materials is not advisable, particularly in the subreflector location, because of possible dielectric heating and consequent fire hazard, as mentioned.

IV. DETAILED TAPING PROCEDURES

There is a precaution which must be observed regarding the instructions which follow: these instructions cannot list every possible location or situation that requires taping. The constant evolution of the external antenna configuration and small differences among the three 64-m antennas in the DSN make it necessary for personnel at each station to make determinations of final detail locations needing tape protection.

All major construction and rework on the antenna main reflector, quadlegs, quadleg base modifications, apex, and tricone must be completed before performing surface preparation and taping. Accumulations of welding rod ends, nuts, bolts, and dirt on the main reflector surface will typically damage a taping job beyond simple repair. It is recommended that the tricone and subreflector taping be completed, with the main reflector taping as the final step. In contrast to this recommendation, however, the following sections are organized with the main reflector procedures first. This is done to clarify the series of carefully considered steps, which build upon previous steps.

A. MAIN REFLECTOR PANEL GAPS AND SEAMS

1. Locations Requiring Tape

- (1) Gaps between all 552 adjacent main reflector panels (additional tape squares required at intersections of gaps).
- (2) Seams between adjacent perforated metal sheets located within a given main reflector panel (on 384 outer perforated-type panels).
- (3) Gaps between main reflector panels and hatch covers.
- (4) Gaps between main reflector panels and quadripod legs.
- (5) Unmodified hatch cover hinges, handle apertures, and other items which are used infrequently (recommended for temporary service only).

2. Surface Preparation Prior to Taping

- (1) Using grinders, dress all panel gaps and seams to eliminate sharp edges that can cut through tape. Radius gap edges as much as possible during grinding operation. During this operation, insure 3 mm (0.12 in.) minimum gaps in fact exist. Use saws or files to create positive gaps where possible interference fits exist, then follow with grinding, as above. Possible loose panel attach hardware should be tightened.
- (2) Using belt sanders with aluminum oxide paper, clean all old paint scale if any, approximately ± 150 mm (6 in.) either side of the panel gaps and seams. Do not remove existing paint to bare metal. Allow for ± 200 mm (8 in.) either side at 4-panel intersections, which will later receive 300 mm (12 in.) tape squares.
- (3) Using carpet cleaners or hand brushes and trisodium phosphate cleaner, scrub the sanded areas. Rinse immediately with a high-pressure water hose and allow to thoroughly dry.
- (4) A determination of need for painting the sanded areas must now be made. Where chipped paint and/or bare metal areas infrequently exist, spot patch painting with Hi-Reflectance white may be adequate. Where bare metal is a frequent problem, or the original layer is suspect for any reason, painting of all sanded areas is strongly advised. This is an important step to assure 0.12-mm (0.005-in.) minimum paint layer under the aluminum tape to follow, for reliable insulation purposes. Tape primer cannot be relied upon to provide reliable insulation.
- (5) Prime the areas along panel gaps and seams with 3M Co. No. 82 tape primer. Allow enough width for later 300-mm (12-in.) tape squares at 4-panel intersections.
- (6) Using tape primer instructions as to setting time, test aluminum tape samples for adequate adhesion. Determine need, if any, for further primer renewing (new coats) just prior to actual taping.

- (7) Tape must be applied very soon after application of primer to insure good adhesion.

3. Taping Procedures

a. General Rules.

- (1) Tape is to be applied to prepared surfaces at 10° C (50° F) or higher ambient temperature (preferably higher).
- (2) Main reflector aluminum tape must be firmly adhered directly to the prepainted and preprimed surfaces for the full tape width. The tape edge must be at least 30 mm (1.25 in.) from the gap as shown in Figures B-1 and B-2.
- (3) Wrinkles and bubbles are to be avoided. The finished tape surface should be smooth and even. Where the direction of taping changes to maintain 30-mm minimum gap coverage (as, for example on a small radius chord) or where a tape roll is used up (as, for example, on a long radial run), the tape is cut square, a seam is made, and the next piece is started in the new direction. The two pieces of aluminum tape comprising a tape seam are insulated from each other and overlapped as shown in Figure B-3. Sharp scissors should be used for clean cuts of all materials.
- (4) Aluminum tape cannot be applied to unpainted metal surfaces or directly to another piece of aluminum tape. The allowed surfaces are properly painted with a minimum thickness of 0.12 mm (0.005 in.) and primed, or insulating surfaces, preferably Kapton tape.
- (5) Aluminum and Kapton tape must be burnished for good adhesion. This step is very important. Too little applied burnishing pressure will result in tape lifting from the surface after a short period (requiring replacement), while very heavy pressure (especially pressure applied directly over the gap) will cause

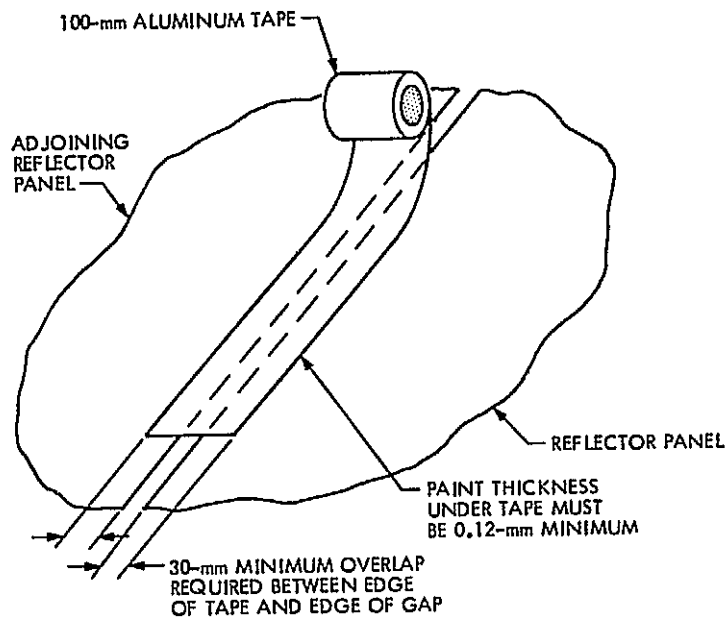


Figure B-1. Main reflector panel gap taping

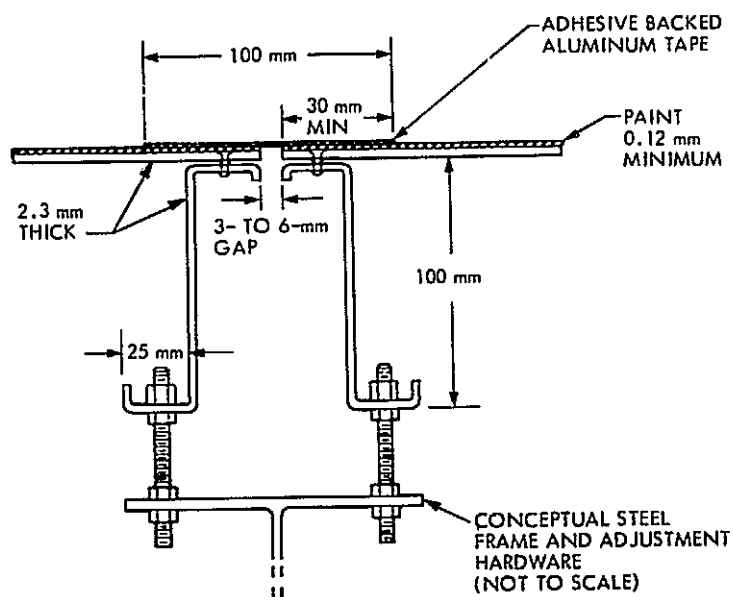


Figure B-2. Cross section, main reflector panel gap taping

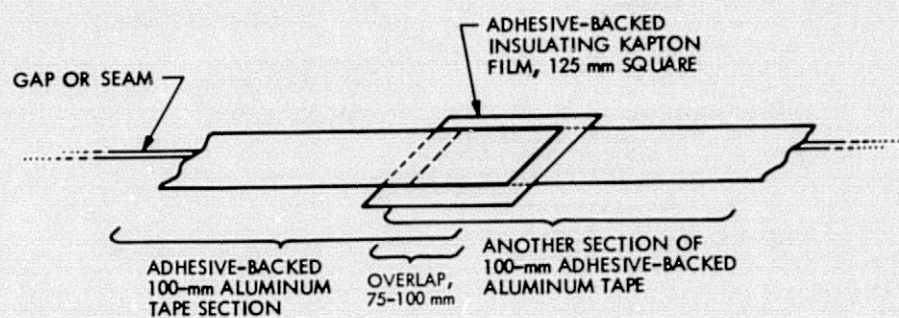


Figure B-3. Overlapped and insulated aluminum tape (main reflector and tricone)

hairline cracks and "punch-throughs" (again requiring replacement). To burnish, use a large spoon-shaped tool, a piece of foam rubber, or just a few pieces of cardboard, hand-held, and used as you would a putty knife. Apply moderate pressure to tape surface to improve adhesion. Use caution on aluminum-surfaced material; excessive burnishing will stretch and tear the material, causing very fine cracks.

b. Step-by-Step Procedure.

- (1) Tape all radial gaps between main reflector panels first, starting at the outside edge of the main reflector. Begin by applying the end of the aluminum tape around and under the edge of the outer panels.
- (2) Two persons form a team for applying aluminum tape. One holds and aligns the roll of tape and moves slowly down the reflector surface toward the vertex (keeping the tape taut by the adhesive pressure only). A spindle or dowel should be used to dispense the material to reduce uneven stretching. The other person follows, centering the tape over the gap and burnishing the tape down carefully to insure proper adherence.
- (3) The tape is applied continuously, following the radial gaps all the way to the inner edge of the main reflector surface. Wherever a roll of tape ends and another is begun, the two pieces are overlapped 75-100 mm (3-4 in.) and insulated from each other with a 125-mm (5-in.) square of Kapton film placed between, as shown in Figure B-3. This technique is used wherever tape ends meet on the main reflector, except for a special case regarding the outer perforated dish panels (see (6) below).
- (4) Next, all chord gaps between circular rows of main reflector panels are taped in the same manner. Provide a 6-mm (0.25-in.) gap between the chord tape ends and the (then existing) radial tapes at all intersections. Remember to handle

any intermediate breaks in the tape as shown in Figure B-3; however, breaks on the relatively short chord tapes are best handled by complete replacement.

- (5) Tape all intersections of 4 panels with Kapton and aluminum tape squares as shown in Figure B-4. First, burnish the 300-mm square of Kapton film directly over the intersection, in a diagonal manner as shown in Figure B-4. Then burnish down a 250-mm aluminum tape square centered on top of the Kapton square. The Kapton film square must extend past the aluminum square at all points a minimum of 20 mm (0.75 in.) to provide reliable electrical insulation as shown in View A-A of Figure B-4. Figure B-5 shows a completed intersection, after final painting. (The preferred diagonal manner of affixing the Kapton and aluminum squares is not shown in this figure. The square manner shown leads to rapid adhesion failures at the corners.)
- (6) The perforated outer main reflector panels are constructed with two perforated metal sheets butted together on the common framework. These butt joints (minor radials) must be taped in the usual way (Figure B-1). These pieces of tape must not contact or pass over the (then existing) chord tapes. These minor radial tapes are trimmed so that a 6-12 mm (0.25-0.50 in.) reliable tape gap exists. Neither Kapton nor aluminum tape squares are necessary in these locations. This is illustrated in Figure B-6. A completely taped portion of the main reflector surface is shown in Figure B-7. (The preferred diagonal placement of Kapton and aluminum squares is not shown in this figure. As mentioned, the square manner illustrated in Figures B-7 and B-5 is no longer recommended.)
- (7) The very large construction gaps between main reflector panels and quadripod legs must first be enclosed with welded plates and angles; the resulting 6-mm interface gaps (main reflector panels to welded plates) must then be ground smooth, painted, primed and taped as shown in Fig. B-8. Several cuts in the tape are made to accommodate

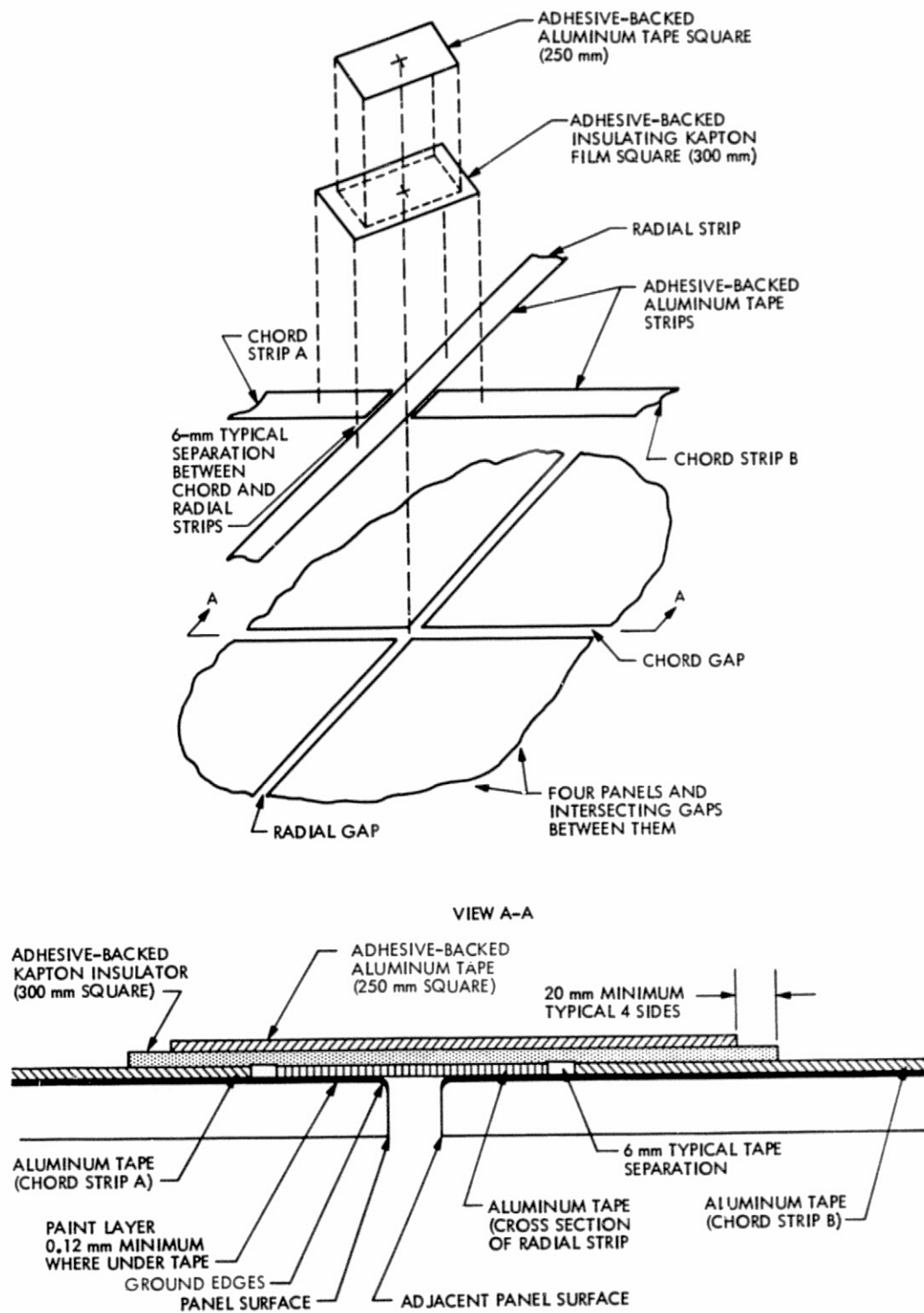


Figure B-4. Main reflector 4-panel intersection taping

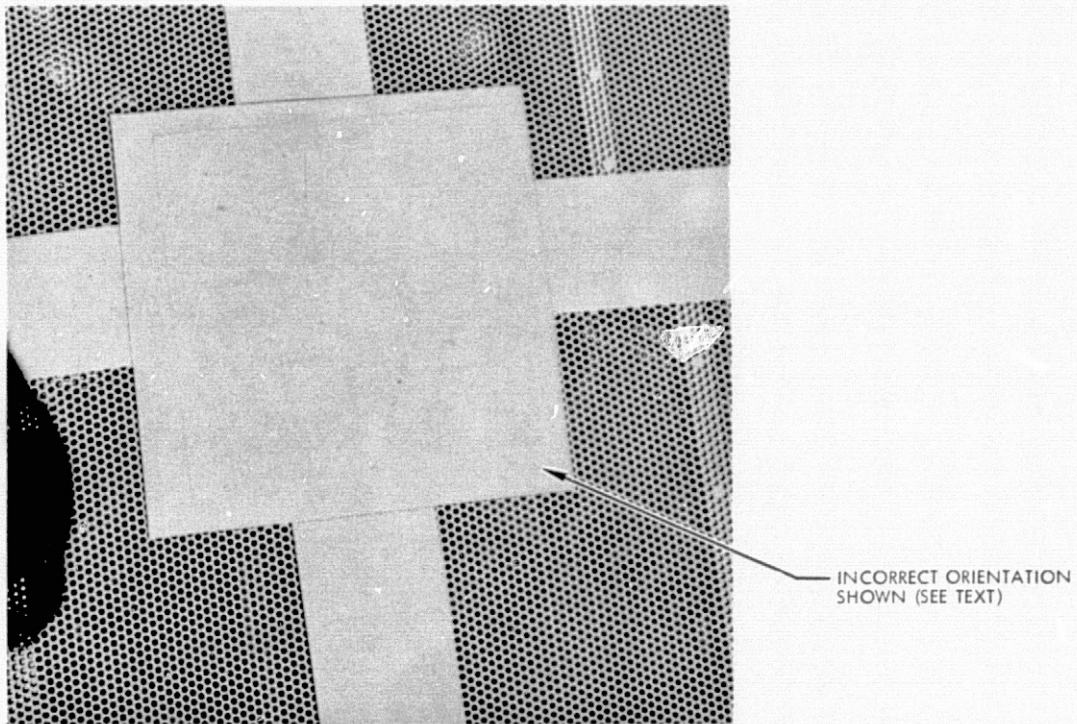


Figure B-5. Main reflector 4-panel intersection tape (photo)

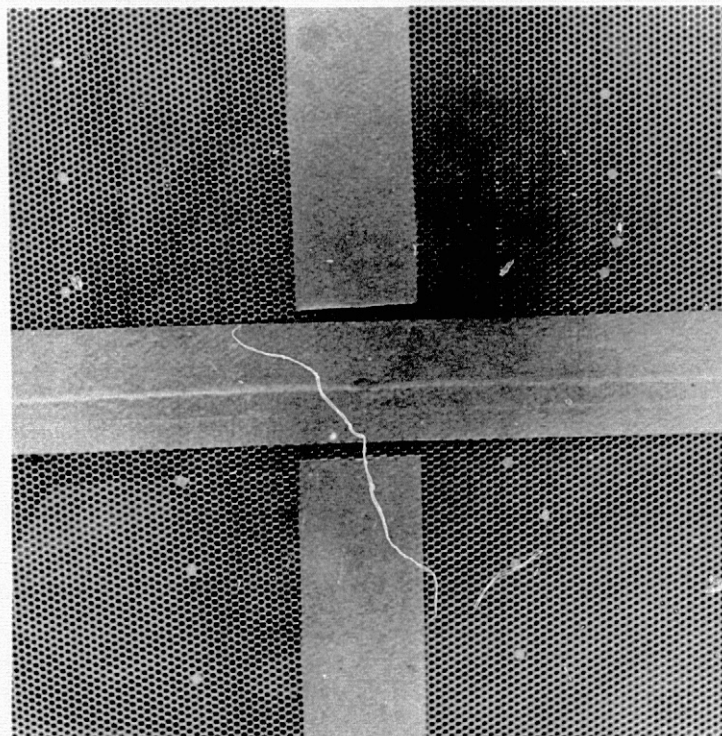


Figure B-6. Main reflector minor radial to chord intersection taping

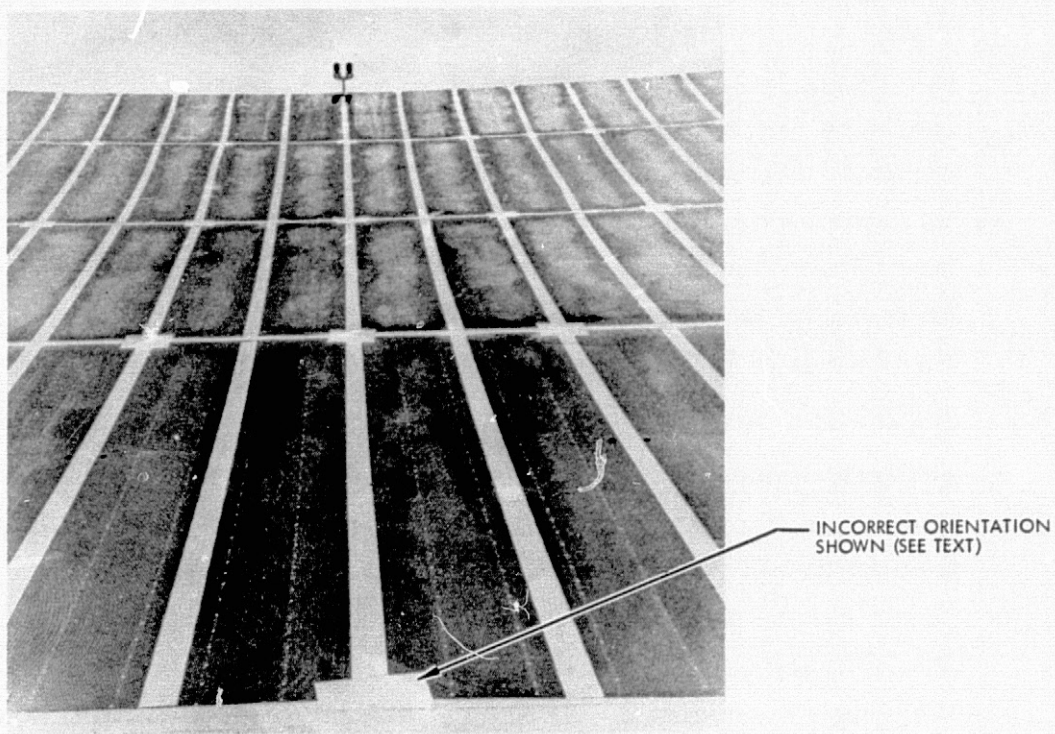


Figure B-7. Main reflector portion completely taped

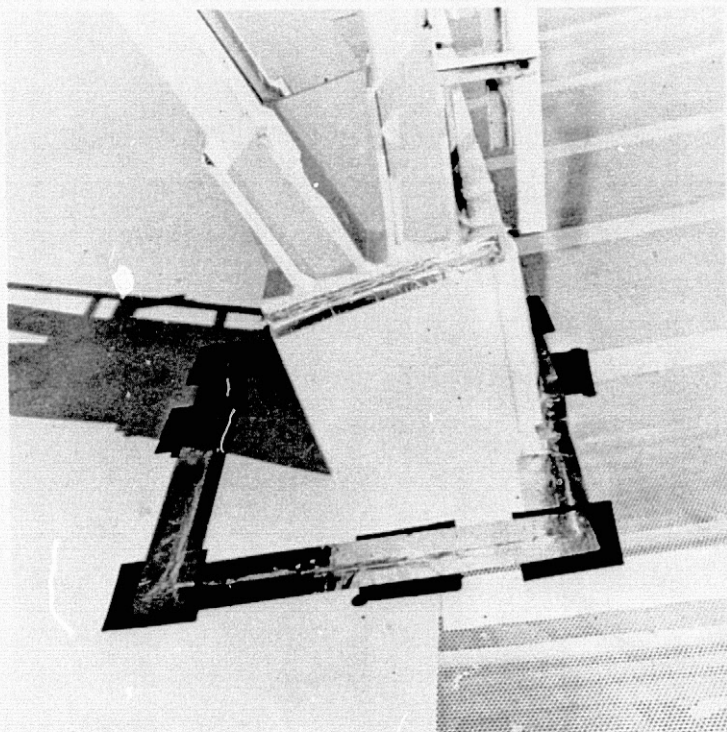


Figure B-8. Quadripod leg to main reflector surface interface taping

changes in taping direction. At each cut, the overlapping/insulating technique shown in Figure B-3 is used. Although the surfaces are not perfectly parallel and typically have irregularities, the tape can still be applied in short sections. Use of Kapton as a substrate as well as an insulator under aluminum tape allows rough gaps to be reliably covered. Wrinkling of the tape can be largely avoided by doing careful work. (Discretion must be used in this area due to anticipated detail differences.)

- (8) Unmodified hatch covers, handles, edges, and hinges must be temporarily taped pending permanent modifications. Wrinkling may be unavoidable in temporary covering of some handles and other protruding hardware. A rectangular cake pan or other sheet metal cover can be used with tape in these areas. Certain of these items are best left uncovered if the wrinkled area is visibly worse than the original problem. Redesigns and modifications in these areas may be required for food noise performance.

4. Painting and Cleanup

- (1) All tape must be painted with Hi-Reflectance white paint immediately after application, while tape surfaces are still clean. Only a very thin (fog) coat of paint, 0.05 mm (0.002 in.) maximum, is desired over the finished aluminum tape squares (and unavoidably over the Kapton as well), to prevent solar reflection and consequent subreflector heating. The more fragile, 100-mm-wide tapes should receive two coats of white paint for protection from weather, sand, etc. Alternately it may be practical to spray-paint only the tape square areas while roller-painting (with one heavier coat) the long 100-mm tapes. The aluminum tapes are not to be etched for improved paint adhesion; etching or soaking with cleaner may damage the thin metal layer.
- (2) A final walkaround visual inspection should be made to verify that tapes are still adhered, free of wrinkles or other damage due to final painting. Waste tape materials, particularly aluminum, loose tools, etc., must be removed from the surface of the reflector. An overview of a completed 64-m main reflector tape installation is shown in Figure B-9.

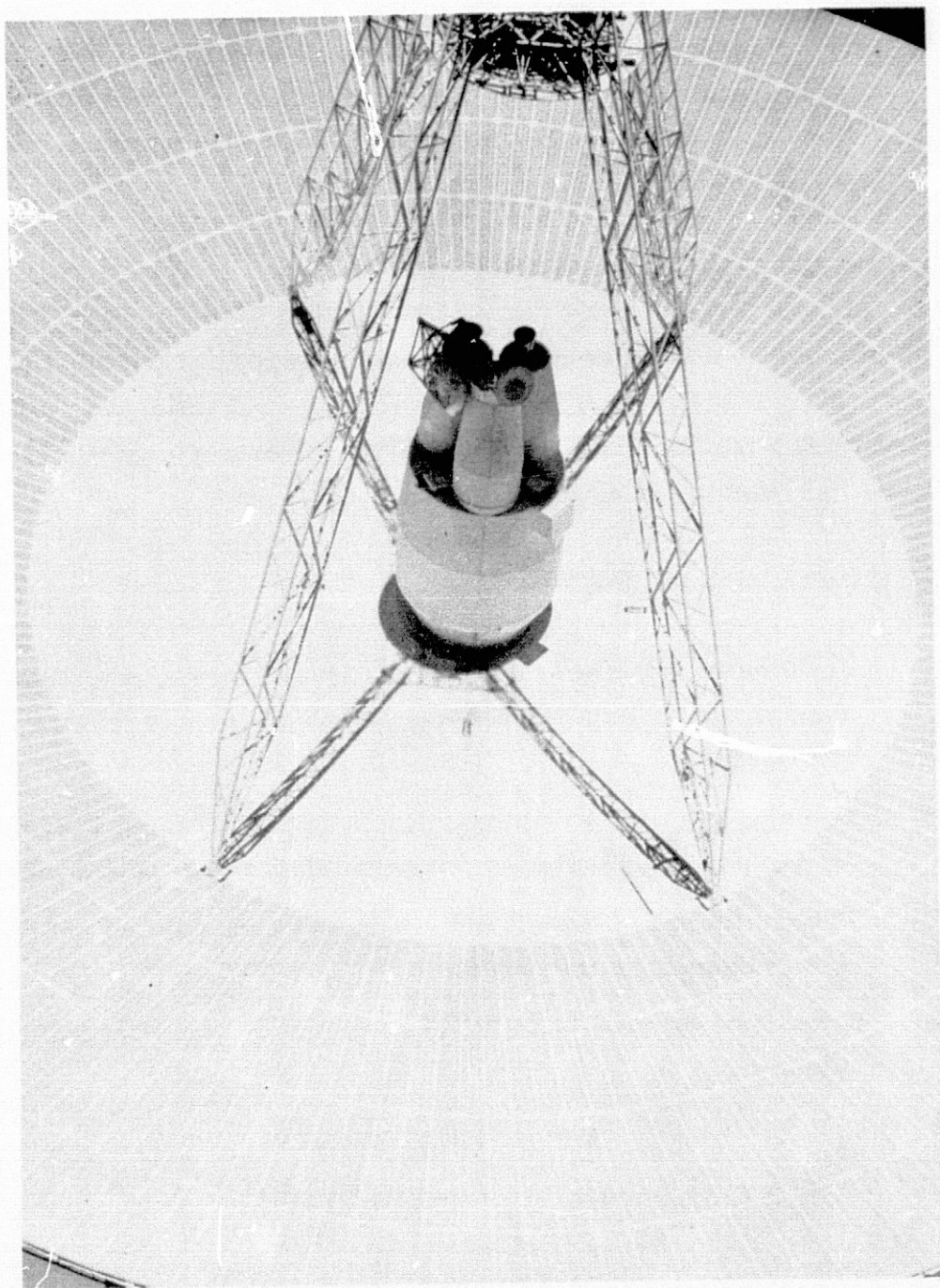


Figure B-9. 64-m main reflector tape installation

- (3) Personnel access to the main reflector surface should be restricted. Painted signs advising general caution and specific walk/no walk zones, at least near the main reflector access door, and other moderate traffic areas, are advised. As mentioned above, tape is fragile and sensitive to foot traffic and equipment movement on the main reflector. Such equipment moves should include tape maintenance planning as a part of the total task.

B. TAPING OF TRICONE STRUCTURE

The tricone area will be difficult to tape because of physical access and shape problems. However, it is closer to the subreflector, with consequent higher illumination power density. Therefore, great care will be required to complete an acceptable job.

1. Locations Requiring Tape

- (1) Unwelded seams between various bolted levels of tricone (except seams between feedcones and tricone which are insulated).
- (2) Tricone hatch cover release latches (needs taping with Kapton only to provide insulation between latch and adjacent metal).
- (3) Tricone doors, hinges, and handles if exposed and not otherwise reworked and/or insulated.
- (4) Other uninsulated, unwelded, or poorly bolted noncontinuous surfaces.
- (5) Cracked welds, rewelding that cannot be done.
- (6) Details such as optical alignment targets.

2. Surface Preparation Prior to Taping

Surface preparation of the tricone structure is similar to previous procedures for the main reflector surface; the steps include the use of surface grinders to remove rough edges, belt sanders to remove loose scale, trisodium phosphate to clean and rinse, and paint and primer to provide insulation and an adhesion base for the tape to follow.

3. Taping Procedures

a. General rules. Same as for main reflector.

b. Step-by-Step Procedure. With the tricone structure, no specific order of work has to be followed. Aluminum tape strips are used over reliably painted seams or cracks, with Kapton tape used as shown previously in Figure B-3 (and possibly Figure B-4). Wrinkles are to be avoided. There may be further occasional use for 250-mm aluminum squares (with or without 300-mm Kapton squares) to cover suspect detailed areas. Again, thin sheet metal forms may be combined with tape to shield different details.

4. Painting and Cleanup

Same procedures as for main reflector.

C. SUBREFLECTOR PANEL GAPS

Because the DSS 14 subreflector was 100% welded, the following procedures have not been fully applied previously. The tape procedures to follow are a result of experience with a similar 64-m antenna subreflector taping, materials RF tests, and extensions of techniques developed for the main reflector surface. The intent is to prevent panel-skin to panel-frame arcing in the detailed gap areas (similar to the main reflector, Figure B-2) and microwave energy leakage through the gap areas into the apex location. Hardware exists in the center region of the apex which is considered totally impractical to bond/insulate/shield.

Primarily, only one taping ground rule previously applied to the main reflector and tricone locations changes at the subreflector; aluminum tape is not allowed over reliably painted subreflector gap areas. Rather, Kapton tape provides, first, a substrate material bridging the gaps for the aluminum tapes to follow, and second, acts as a dielectric to prevent microwave breakdown between the aluminum tape edges and the subreflector panel skins. Also, the backsides of the subreflector gap areas are filled with resilient material. This material serves two functions: (1) it deters oil, water, and debris collection and entrapment in the nominally upside down (compared with main reflector) gap areas, and (2) in conjunction with the Kapton substrate tape on the frontside, stiffens and dampens differential panel movements and vibrations due to the nearly 2-m spans between framework attach points. By these steps, it is expected that previous aluminum tape fractures in this location will be eliminated.

A buildup on the frontside of the subreflector of paint, Kapton, or aluminum materials will reduce the effectiveness of the bypass capacitor/shield system, so an absolute minimum number of overlays or buildup is required and designed into the following procedures. Carefully followed procedures will result in no more than two layers of Kapton plus two layers of aluminum tape at the most complex intersections. Further, careful adherence to procedures will provide maximum physical captivation of longer tape pieces, inhibiting possible loose tapes and causing resultant antenna gain and noise performance degradation.

1. Preparations

- (1) Correct all sources of oil leaks or fluid contamination before starting further work on any portion of the subreflector system. Finish all apex welding or other modification/maintenance which might contribute debris during or immediately after the subreflector work. Complete work on installation of the insulated optical alignment hole plugs.
- (2) Clean the rear and front surfaces of all oil, dirt, welding rod ends, metal chips, etc. Steam cleaning, vacuuming, handpicking, wire brushing, etc., are suggested methods.

- (3) Torque all panel mounting bolts and brackets to specification. Verify that all hardware is in place. A loose panel mounting bolt will typically ruin carefully applied tape.
- (4) Complete all possible work required on the subreflector diffraction shield installation before attempting to tape the front surface in order to minimize flexing damage to the tape caused by walking or working on the back side. The subreflector and diffraction shield are to be taped as one complete unit.
- (5) Remove all old tape.
- (6) Remove all old adhesive, paint scale, or excessive paint buildup by sanding with aluminum oxide paper or paint-stripping the entire surface.
- (7) Provide 3-mm (0.12-in.) minimum reliable gaps between panel edges by sawing or filing where necessary.
- (8) Dress all panel edges on the front surface to avoid tape punctures. Polish out all burrs and rough spots with aluminum oxide paper. Clean and degrease gap areas on both sides of the subreflector.
- (9) Temporarily retape panel gaps with 75-mm (3-in.) cloth tape.
- (10) The panel gaps are to be filled from the rear with a 3-mm (0.12-in.) thick bead of RTV material to provide a flush surface on the front side. Do not apply in damp or rainy weather. After a 48-hr cure time, follow with a second 3-mm layer; 24-hr later, a third layer. Material applied over 3-mm thickness will require longer cure times.
- (11) Remove the temporary cloth tape and, using a razor blade, trim any material on the frontside protruding through the gap. Fill any voids found in the front surface. Remove any other material that might have leaked around the edges by scraping and hand-sanding with aluminum oxide paper.

- (12) Assess the need for priming/painting according to surface condition resulting from step (6). If the entire subreflector was paint stripped (perhaps the easiest method under the difficult elevated scaffolding conditions or, for example, to avoid excessive paint buildup), it should now be treated with appropriate aluminum metal primer.
- (13) Then, paint the areas along all panel gaps or other locations to receive tape, using Hi-Reflectance white. Remember to allow for 125-mm (5-in.) tape width as well as chord tape overlaps to follow; 0.12-mm (0.005-in.) paint thickness is recommended. (The complete surface may be painted at this time.)
- (14) Allow paint to adequately dry. After paint is dry, test tape primer samples for adequate adhesion. Determine need, if any, for possible light hand-sanding and/or cleaning to provide good tape primer adhesion.
- (15) Integrate, with consideration for tape primer setting time, the following section with tape primer application.

2. Kapton Substrate

- (1) The 125-mm (5-in.) Kapton tape must only be applied to proper tape primed surfaces at 10°C (50°F) or higher ambient temperature (preferably higher).
- (2) Premeasure gap lengths to be covered and cut tape to match with some extra material. Remove backing material at ends where applicable; cut and replace tabs to allow later trimming. Chamfer all corners 6 mm (0.25 in.) by 45° (see Figure B-10).
- (3) Start at the center of the subreflector and cover primed radial gaps first; peel the backing material tab off; line up the tape with the gap and apply symmetrically, smoothing the tape towards the outside edge of the subreflector. Burnish carefully for good adhesion. Working from a fixed elevated position, use the subreflector rotational motors to bring new radial gaps, in turn, within working range (see Figure B-11).

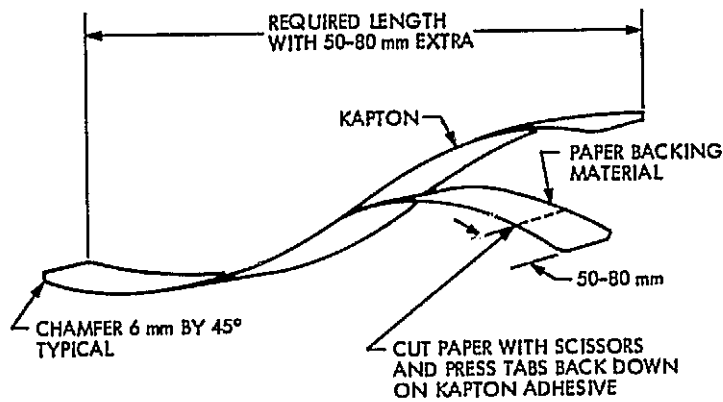


Figure B-10. Subreflector substrate tape preparation

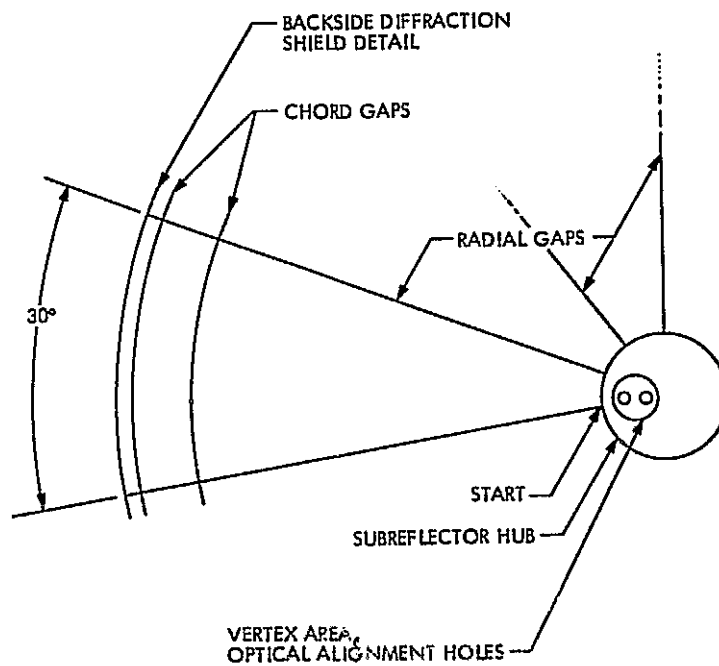


Figure B-11. Subreflector substrate tape locations, plan view

- (4) Avoid tape wrinkles, bubbles, or suspected poor adhesion zones. Remove and replace any questionable piece. Determine treatment required at the ends of the radial gaps, depending upon diffraction shield details. Wraparound of the radial tapes onto the backside is preferred if feasible.
- (5) Add Kapton chord pieces symmetrically according to Figure B-12. Carefully trim the chord pieces with an Exacto or equivalent knife where two pieces meet. The Kapton material is not to overlap and an 0.8-mm (0.03-in.) gap is preferred rather than creating a buildup. Do not cut through the Kapton into the paint. Tabs left on the Kapton prior to cutting with the knife will prevent paint cut-throughs. The Kapton material edges must never be closer than 40 mm (1.5 in.) from a panel chord gap (or a radial gap, for that matter).
- (6) Burnish all chord pieces; inspect for proper adhesion and lack of buildup. Then lightly wipe clean with Freon or alcohol to remove oil or dirt accumulated during installation, being careful not to dampen tape adhesive underneath.
- (7) Although tape primer (to improve adhesion of the following aluminum tapes) may be applied over the Kapton substrate tapes it is not recommended. Test areas should be tried at this point.

3. Aluminum Tape and Intertape Insulators

- (1) The 100-mm (4-in.) aluminum tape must only be applied to clean dry Kapton surfaces at 10 deg C (50 deg F) or higher ambient temperature (preferably higher).
- (2) Start by covering all chord ends ("first aluminum tape layers" in Fig. B-13). Chamfer aluminum tape ends 3 mm (0.12 in.) by 45 deg. Begin aluminum tape 6 mm (0.25 in.) from a radial gap and work symmetrically from two radials towards the panel center (see Fig. B-13). Provide 25 mm (1 in.) minimum from the aluminum tape edge to the underlying panel gap, or 15 mm (0.6 in.) minimum from the aluminum tape edge to the properly applied underlying Kapton; in either case, the Kapton and aluminum tapes should be parallel, with equal edges of Kapton exposed.

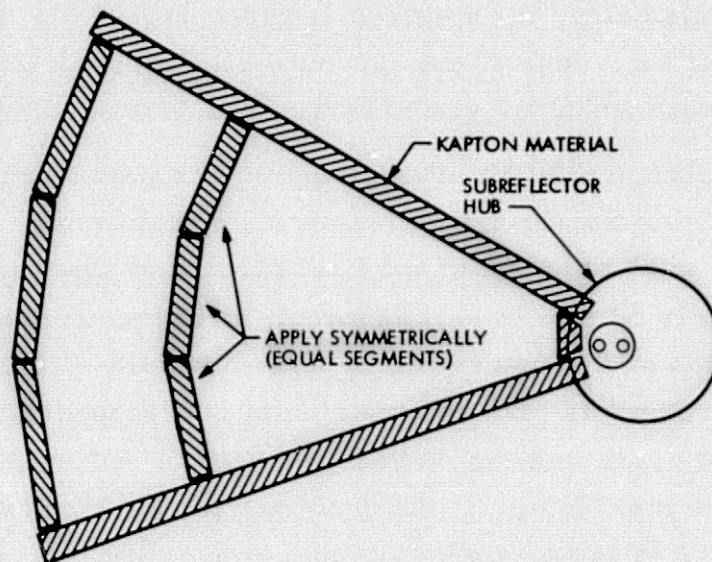


Figure B-12. Subreflector substrate tape layout

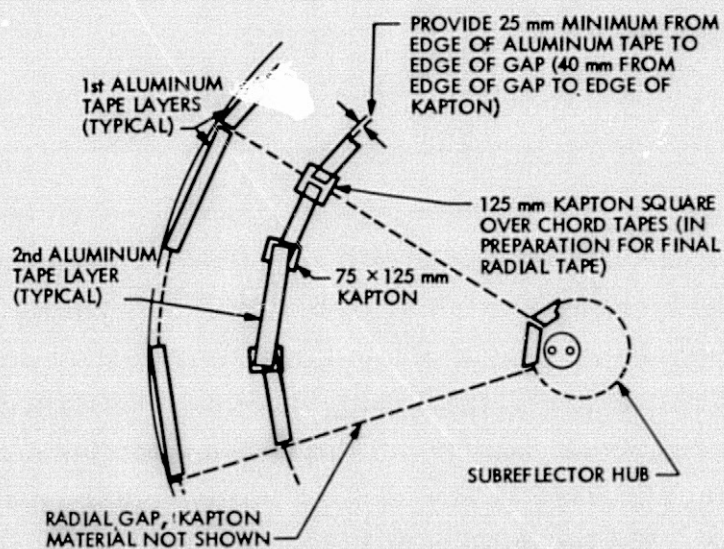


Figure B-13. Subreflector aluminum tape layout

- (3) Carefully burnish the first layer aluminum tapes. Hairline fractures in this location will develop microwave noise and must be eliminated. Replace any questionable aluminum tapes. As a general rule, do not burnish directly over a gap; rather, burnish along each side of the gap, say 40 mm (1.5 in) inwards from each edge of the 100-mm-wide aluminum tape, with allowance for the chord vs straight-line asymmetries.
- (4) Add the second aluminum tape layers next (Figure B-13). Begin by applying Kapton tape insulators 75 × 125 mm (3 × 5 in.) symmetrically over the ends of the first aluminum tape layers, with approximately 50 mm (2 in.) on top of the aluminum and 25 mm (1 in.) on top of the underlying Kapton substrate. The second aluminum tape layer is then symmetrically overlapped onto the insulated first aluminum tape layer 40 mm (1.5 in.) such that a minimum of 12 mm (0.5 in.) of Kapton surface barrier exists between the first and second aluminum tape layers. Remove and replace any questionable second aluminum tape layers at this point, even if it means replacing the Kapton tape insulators and first aluminum tape layers. This is one of the most difficult sub-reflector taping areas to handle.
- (5) Carefully burnish finalized second-layer aluminum tapes according to previous procedures.
- (6) A series of aluminum tape butt joints spaced approximately 12 mm (0.50 in.) wide will now be apparent at all chord tape intersections located at radial gaps (Figure B-13). These are covered symmetrically and in square fashion with precut (from the roll material) and preprepared (possibly with quick release backings) 125-mm (5-in.) square Kapton insulators. A single aluminum tape is now applied to the radial gaps, symmetrically on the Kapton substrate and over the 125-mm squares from the center hub to (and possibly around) the outer rim (onto the backside), depending on detail steps taken in Section 2 (4). Overlaps on any radial (due to an empty roll of aluminum tape, for example) are not allowed. Rather, begin radials with known sufficient rolls.

- (7) Burnish all radial aluminum tapes according to prior practice.
- (8) The small optical alignment holes are to be covered with a disk of Kapton and then aluminum tape material. Provide 12 mm (0.5 in.) minimum surface barrier across the Kapton from the aluminum tape to the painted aluminum panel. (This final covering is done after installation of the insulated alignment plugs is completed.)
- (9) The (flush) vertex plate area must be covered with a similar series of Kapton substrates and insulated aluminum tapes. Caution must be exercised during each step to prevent buildups of materials as above.
- (10) A very careful inspection for aluminum tape fractures, good adhesion, and adequate surface barriers across all insulating tapes should now be made. Possible waste materials must be removed. Aluminum and Kapton tape surfaces can now be cleaned very lightly with Freon or alcohol in preparation for final painting. Again care must be exercised not to dampen tape adhesive near the edges. The aluminum surfaces are not to be etched.

4. Painting and Cleanup

- (1) Only a thin (fog) coat of Hi-Reflectance white paint, 0.05 mm (0.002 in.) is suggested for protection of the thin aluminum material. Determine need of further paint based on steps taken in 1 (13). While the exposed Kapton needs no paint, it will (unavoidably) be painted as part of the operation.
- (2) Verify that the rain water drain holes are open in the surface.
- (3) Any remaining (or future) work on the backside of the subreflector should proceed very carefully; kneeboards or scaffolding should be used to preclude fracture of the fragile frontside tapes.
- (4) Paint general caution and specific no walk signs on the subreflector backside areas and restrict access.
- (5) A final visual inspection after all work is completed is recommended.

V. MAINTENANCE

A visual inspection of the main reflector and tricone surfaces can be made with a walkaround survey. The tape should be replaced if 2/3 of the width between the tape edge and the gap is free (loose). Any torn or cut tape should be also be replaced. Kapton film overlaps, according to previous practice, are required with main reflector aluminum tape patches to continue insulation requirements. Local hand sanding with aluminum oxide paper to restore the paint surface and tape primer will be required for repair. Repainting on small repaired sections is not a noise-reduction requirement.

A visual inspection of the subreflector surface can be made from one quadleg ladder and by rotating the subreflector. Tape replacement should be done at any time a piece even begins to come loose. The loose piece must be completely replaced, in contrast to the main reflector approved patches. The procedure given within the above section captivates most of the pieces. Inspections might concentrate on the second aluminum tape layers (which are not captivated), and the long radial tapes. A close visual inspection may be required to check on small longitudinal cracks in the aluminum tape surface if microwave noise, traced to the outdoor area, is a later problem. A telescope may be used for remote inspection. Oil leaks from the subreflector positioning components should be repaired immediately to preclude seepage to the front surface. As mentioned, the subreflector taping procedures have not been fully applied previously. Careful maintenance inspections during the first weeks or months following completion are recommended until confidence allows less frequent attention.

During the above visual inspections, attention to the following additional details is advised:

- (1) Broken welds, especially on quadripod legs and apex
- (2) Loose metal or other refuse
- (3) Misplaced tools, unstowed hardware
- (4) Cleanliness of insulators (S/X feed, feedcone doors, feedhorn flanges where applicable)
- (5) Feedhorn windows